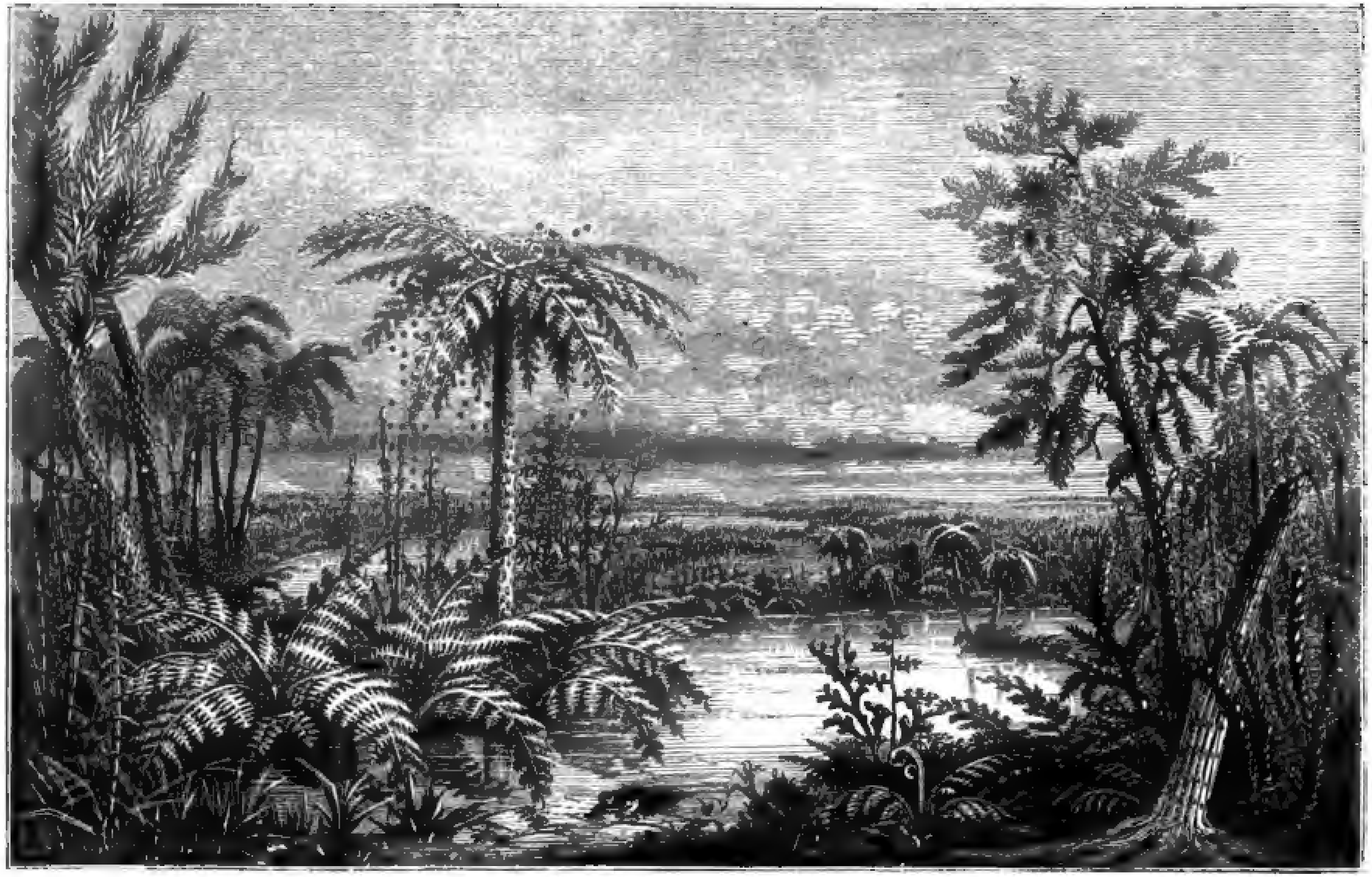
MANUAL OF GEOLOGY.



CARBONIFEROUS AGE.—Pages 283 and 333.

MANUAL

OF

GEOLOGY:

TREATING OF THE PRINCIPLES OF THE SCIENCE

WITH SPECIAL REFERENCE TO

AMERICAN GEOLOGICAL HISTORY,

FOR THE USE OF COLLEGES, ACADEMIES, AND SCHOOLS OF SCIENCE.

BY

JAMES D. DANA, M.A., LL.D.

SILLIMAN PROFESSOR OF GEOLOGY AND NATURAL HISTORY IN YALE COLLEGE; AUTHOR OF "A SYSTEM OF MINERALOGY," OF REPORTS OF WILKES'S EXPLORING EXPEDITION ON GEOLOGY, ON ZOOPHYTES, AND ON CRUSTACEA, ETC.

Licet jam oculis quodammodo contemplari pulchritudinem rerum earum,
quas divina providentia dicimus constitutas.—Cic.
Nunquam aliud natura aliud sapientia dicit.—Juv.

ILLUSTRATED BY A CHART OF THE WORLD, AND OVER ONE THOUSAND FIGURES, MOSTLY FROM AMERICAN SOURCES.

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PREFACE.

Two reasons have led the author to give this Manual its American character: a desire to adapt it to the wants of American students, and a belief that, on account of a peculiar simplicity and unity, American Geological History affords the best basis for a text-book of the science. North America stands alone in the ocean, a simple isolated specimen of a continent (even South America lying to the eastward of its meridians), and the laws of progress have been undisturbed by the conflicting movements of other lands. The author has, therefore, written out American Geology by itself, as a continuous history. Facts have, however, been added from other continents so far as was required to give completeness to the work and exhibit strongly the comprehensiveness of its principles.

It has been the author's aim to present, for study, not a series of rocks with their dead fossils, but the successive phases in the history of the earth,—its continents, seas, climates, life, and the various operations in progress. Dynamical Geology, contrary to the views of some geologists, has been placed after the stratigraphical or historical portion. It will, however, be found that through the latter the facts have been followed by statements and explanations of principles; so that the student, on reaching the pages treating of Geological Causes, will have already learned much of what they contain.

As many readers may not be familiar with Zoology, a review of the classification of animals, with many illustrations, has been given before entering upon the Dynamical History of the ancient life of the world.

The Manual has been adapted to two classes of students,—the literary and scientific,—by printing the details in finer type. The convenience of a literary class has been further provided for by the addition of a brief synopsis of the work, in which each head is made to present a subject, or question, for special attention.

In the preparation of the American part of the volume, the author has freely used the reports of the various geological surveys of the country, the memoirs published in the different scientific journals and transactions, and other works bearing on the subject. He has also drawn from his own Memoirs and Exploring Expedition Reports, especially on the subjects of Coral islands,—Volcanic islands,—the Formation of Valleys by the action of rivers,—the General Features of the Globe, and their origin,—American Geological history,—and the Temperature of the Globe, as exhibited on the Physiographic Chart.

The illustrations of American Palæozoic life have been largely copied from the Reports of Professor HALL. A few of the Palæozoic figures, and many of later periods, are from original drawings made by Mr. F. B. MEEK, to whose artistic skill and palæontological science the work is, throughout, greatly indebted. The drawings were nearly all made on the wood for engraving by Mr. Meek; and the palæontological pages have had the benefit of his revision. The name of the engraver, LOCKWOOD SANFORD, of New Haven, also deserves mention in this place.

In selecting figures of foreign fossils for the Manual, those used in Lyell's and other standard English works have, with few exceptions, been avoided, so that the student owning any of those volumes will have additional illustrations of the science. Many of the foreign figures are from the beautifully illustrated "Paléontologie et Géologie" of Alcide d'Orbigny.

The author would make acknowledgments to his countrymen for the readiness with which they have furnished aid, whenever appealed to, and especially, for oft-repeated favors, to J. P. LESLEY, of Philadelphia; J. S. NEWBERRY, of Cleveland, Ohio; ARNOLD GUYOT, of Princeton, N.J.; L. LESQUEREUX, of Columbus, Ohio; E. BILLINGS, of Montreal, Canada; E. JEWETT,

of Albany, N.Y.; and W. C. MINOR and FRANK H. BRADLEY, of New Haven. Mr. Bradley has given freely his constant assistance during the progress of the work through the press.

The author has endeavored to bring the volume into as small a compass as is consistent with a proper exhibition of the science; and if some find its pages too numerous, he feels confident that quite as many would prefer greater fulness. The details introduced have seemed to be necessary in order that the march of events might be appreciated.

Geology is rapidly taking its place as an introduction to the higher history of man. If the author has sought to exalt a favorite science, it has been with the desire that man—in whom geological history had its consummation, the prophecies of the successive ages their fulfilment—might better comprehend his own nobility and the true purpose of his existence.

NEW HAVEN, CT., November 1, 1862.

TO INSTRUCTORS.

THE "Brief Synopsis" of Appendix I. is intended to facilitate the use of this Manual as a recitation-book. Lectures cannot well be wholly dispensed with in the instruction of Natural or Physical Science; but, with a work so full of illustrations as this, they may, with great advantage, be altogether subordinate to recitations, especially if the latter are accompanied with an exhibition of specimens. Through the use of fine type for the details of the Science, the Manual is made to combine in one a small and a large book. The topics presented in the "Synopsis" are, with few exceptions, those of the former; and they are so prepared that each suggests a question. A cursory perusal of the details in the smaller type is, however, to be advised, as it will aid the student in acquiring precise ideas. Even in scientific schools it may be best that the student first go through the Manual with the Synopsis, and then, in a second course, take up the Palæontology and Dynamics with greater thoroughness.

Every Academy or other Institution teaching the Science should have, at least, a small collection of specimens. Even twenty-five dollars will purchase one (of Louis Sæmann, Paris, 45 Rue St. André-des-Arts, or of Dr. A. Krantz, at Bonn on the Rhine) containing specimens of nearly all the mineral species mentioned in the Manual, and of the more common kinds of rocks, and another twenty-five dollars, a collection of fossils that would be of great service.

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INTRODUCTION.

PART I.—Physiographic Geology.

PART II.—Lithological Geology.

PART III.—Historical Geology.

PART IV.—Dynamical Geology.

LIST OF ABBREVIATIONS.

Ag.—L. Agassiz.
B.—E. Billings.
Brngt.—Brongniart.
Con.—T. A. Conrad.
D'Orb.—Alcide d'Orbigny.
D.—J. D. Dana.
E. & H.—Edwards & Haime.
Ehr.—Ehrenberg.
Göpp.—Göppert.
H.—J. Hall.
H. & M.—Hall & Meek.
Hk.—E. Hitchcock.
L.—J. Leidy.
Lam.—Lamarck.
Lsqx.—L. Lesquereux.
Linn.—Linnæus.
M.—F. B. Meek.
M. & H.—Meek & Hayden.
Schp.—Schimper.
Shum.—Shumard.
Sow.—Sowerby.
Sternb.—Sternberg.
Suck.—Suckow.
T. & Hs.—Tuomey & Holmes.
Ung.—Unger.
Van.—L. Vanuxem.

INTRODUCTION.

1. **Kingdoms of nature.**—SCIENCE, in her survey of the earth, has recognized three kingdoms of nature,—the animal, the vegetable, and the inorganic; or, naming them from the forms characteristic of each, the ANIMAL-KINGDOM, the PLANT-KINGDOM, and the CRYSTAL-KINGDOM. An individual in either kingdom has its systematic mode of formation or growth.

The plant or animal, (1) endowed with life, (2) commences from a germ, (3) grows by means of imbibed nutriment, and (4) passes through a series of changes and gradual development to the adult state, when (5) it evolves new seeds or germs, and (6) afterward continues on to death and dissolution.

It has, hence, its cycle of growth and reproduction, and cycle follows cycle in indefinite continuance.

The crystal is (1) a lifeless object, and has a simpler history: it (2) begins in a nucleal molecule or particle; (3) it enlarges by external addition or accretion alone; and (4) there is, hence, no proper development, as the crystal is perfect, however minute; (5) it ends in simply existing, and not in reproducing; and, (6) being lifeless, there is no proper death or necessary dissolution.

Such are the individualities in the great kingdoms of nature displayed upon the earth.

2. But the earth also, according to Geology, has been brought to its present condition through a series of changes or progressive formations, and from a state as utterly featureless as a germ. Moreover, like any plant or animal, it has its special systems of interior and exterior structure, and of interior and exterior conditions, movements, and changes; and, although Infinite Mind has guided all events towards the great end,—a world for mind,—the earth has, under this guidance and appointed law, passed through a regular course of history or growth. Having, therefore, as a sphere, its comprehensive system of growth, it is a unit or individuality, not, indeed, in either of the three kingdoms of nature which have been mentioned, but in a higher,—a WORLD-KINGDOM.

Every sphere in space must have had a related system of growth, and all are, in fact, individualities in this Kingdom of Worlds.

Geology treats of the earth in this grand relation. It is as much removed from Mineralogy as from Botany and Zoology. It uses all these departments; for the species under them are the objects which make up the earth and enter into geological history. The science of minerals is more immediately important to the geologist, because aggregations of minerals constitute rocks, or the plastic material in which the records of the past were made.

3. The earth, regarded as such an individuality in a world-kingdom, has not only its comprehensive system of growth, in which strata have been added to strata, continents and seas defined, mountains reared, and valleys, rivers, and plains formed, all in orderly plan, but also a system of currents in its oceans and atmosphere,—the earth's circulating-system; its equally world-wide system in the distribution of heat, light, moisture, and magnetism, plants and animals; its system of secular variations (daily, annual, etc.) in its climate and all meteorological phenomena. In these characteristics the sphere before us is an individual, as much so as a crystal or a tree; and, to arrive at any correct views on these subjects, the world must be regarded in this capacity. The distribution of man and nations, and of all productions that pertain to man's welfare, comes in under the same grand relation; for in helping to carry forward man's progress as a race the sphere is working out its final purpose.

There are, therefore,

4. **Three departments of science arising out of this individual capacity of the earth.**

I. Geology, which treats of (1) the earth's structure, and (2) its system of development,—the last including (1) its progress in rocks, lands, seas, mountains, etc.; (2) its progress in all physical conditions, as heat, moisture, etc.; (3) its progress in life, or its vegetable and animal tribes.

II. Physiography, which begins where Geology ends,—that is, with the adult or finished earth,—and treats (1) of the earth's final surface-arrangements (as to its features, climates, magnetism, life, etc.), and (2) its system of physical movements or changes (as atmospheric and oceanic currents, and other secular variations in heat, moisture, magnetism, etc.).

III. The earth with reference to man (including ordinary Geography): (1) the distribution of races or nations, and of all productions or conditions bearing on the welfare of man or nations; and (2) the progressive changes of races and nations.

The first considers the structure and growth of the earth; the second, its features and world-wide activities in its finished state; the third, the fulfilment of its purpose in man, for whose pupilage it was made.

5. **Relation of the earth to the universe.**—While recognizing the earth as a sphere in a world-kingdom, it is also important to observe that the earth holds a very subordinate position in the system of the heavens. It is one of the smaller satellites of the sun,—its size about 1-1400,000th that of the sun. And the planetary system to which it belongs, although 3,000,000,000 of miles in radius, is but one among myriads, the nearest star 7000 times farther off than Neptune. Thus it appears that the earth is a very little object in the universe. Hence we naturally conclude that the earth is but a dependent part of the solar system; that as a satellite of the sun, in conjunction with other planets, it could no more have existed before the sun, or our planetary system before the universe of which it is a part, than the hand before the body which it obediently attends.

Although thus diminutive, the laws of the earth are the laws of the universe. One of the fundamental laws of matter is gravitation; and this we trace not only through our planetery system, but among the fixed stars, and thus *know* that one law pervades the universe.

The rays of light which come in from the remote limits of space are a visible declaration of unity; for this light depends on molecular vibrations,—that is, the ultimate constitution and mode of action of matter; and by the identity of its principles or laws, whatever its source, it proves the essential identity of the molecules of matter.

Meteoric stones are specimens of celestial bodies occasionally sent to us from the heavens. They exemplify the same chemical and crystallographic laws as the rocks of the earth, and have afforded no new element or principle of any kind.

The moon presents to the telescope a surface covered with the craters of volcanoes, having forms that are well illustrated by some of the earth's volcanoes, although of immense size. The principles exemplified on the earth are but repeated in her satellite.

6. Thus, from gravitation, light, meteorites, and the earth's satellite, we learn that there is oneness of law through space. The elements may differ in different systems, but it is a difference such as exists among known elements, and could give us no new fundamental laws. New crystalline forms might be found in the depths of space, but the laws of crystallography would be the same that

are displayed before us among the crystals of the earth. A text-book on Crystallography, Physics, or Celestial Mechanics, printed in our printing-offices, would serve for the universe. The universe, if open throughout to our explorations, would vastly expand our knowledge, and science might have a more beautiful superstructure, but its basement-laws would be the same.

The earth, therefore, although but an atom in immensity, is immensity itself in its revelations of truth; and science, though gathered from one small sphere, is the deciphered law of all spheres.

It is well to have the mind deeply imbued with this thought before entering upon the study of the earth. It gives grandeur to science and dignity to man, and will help the geologist to apprehend the loftier characteristics of the last of the geological ages.

7. **Special aim of geology, and method of geological reasoning.**—Geology is sometimes defined as the science of the structure of the earth. But the ideas of structure and *origin* of structure are inseparably connected, and in all geological investigations they go together. Geology had its very beginning and essence in the idea that rocks were made through secondary causes; and its great aim has ever been to study structure in order to comprehend the earth's history. The science, therefore, is a historical science. It finds strata of sandstone, clay-rock, and limestone, lying above one another in many successions; and, observing them in their order, it assumes, not only that the sandstones were made of sand by some slow process, clayey rocks of clay, and so on, but that the strata were *successively* formed; that, therefore, they belong to *successive periods* in the earth's past; that, consequently, the *lowest* beds in a series were the *earliest* beds. It hence infers, further, that each rock indicates some facts respecting the condition of the sea or land at the time it was formed, one condition originating sand deposits, another clay deposits, another lime,—and, if the beds extend over thousands of square miles, that the several conditions prevailed uniformly to this same extent at least. The rocks are thus regarded as records of successive events in the history,—indeed, as actual historical records; and every new fact ascertained by a close study of their structure, be it but the occurrence of a pebble, or a seam of coal, or a bed of ore, or a crack, or any marking whatever, is an addition to the records, to be interpreted by careful study.

Thus every rock marks an epoch in the history; and groups of rocks, periods; and still larger groups, ages; and so the ages which

reach through geological time are represented in order by the rocks that extend from the lowest to the uppermost of the series.

8. If, now, the great beds of rock, instead of lying in even horizontal layers, are much folded up, or lie inclined at various angles, or are broken and dislocated through hundreds or thousands of feet in depth, or are uplifted into mountain-elevations, they bear record of still other events in the great history; and should the geologist, by careful study, learn how the great disturbance or fracture was produced, or succeed in locating its time of occurrence among the epochs registered in the rocks, he would have interpreted the record, and added not only a fact to the history, but also its full explanation. The history is, hence, a history of the upturnings of the earth's crust, as well as of its more quiet rock-making.

If, in addition, a fossil shell, or coral, or bone, or leaf, is found in one of the beds, it is a relic of some species that lived when that rock was forming; it belongs to that epoch in the world represented by the particular rock containing it, and tells of the life of that epoch; and if numbers of such organic remains occur together, they enable us to people the seas or land, to our imagination, with the very life that belonged to the ancient epoch.

Moreover, as such fossils are common in a large number of the strata, from the lowest containing signs of life to the top,—that is, from the oldest beds to the most recent,—by studying out the characters of these remains in each, we are enabled to restore, to our minds, to some extent, the population of all the epochs as they follow one another in the long series. The strata are thus not simply records of moving seas, sands, clays, and pebbles, and disturbed or uplifted strata, but also of the living beings that have in succession occupied the land or waters. The history is a history of the life of the globe, as well as of its rock-formations; and the life-history is the great topic of Geology: it adds tenfold interest to the other records of the dead rocks.

These examples are sufficient to explain the basis and general bearing of geological history.

The method of interpreting the records rests upon the simple principle that rocks were made as they are now made, and that life lived in olden time as it now lives; and, further, the mind is forced into receiving the conclusions arrived at by its own laws of action.

For example, we go to the sea-shore, and observe the sands thrown up by the waves; note how the wash of the waves brings in layer upon layer, though with many irregularities; how the progressing waters raise ripples over the surface, which the next wave buries beneath other sands; how such sand-beds gradually

increase in extent; how they are often continued out scores of miles beneath the sea, as the bottom of the shallow shore-waters; and that these submerged beds are formed through constant depositions from the ever-moving waters. Then we go among the hard rocks, and find strata made of sand in irregular layers, much like those of the beach; and on opening some of the layers we discover ripple-marks covering the surface, as distinct and regular as if just made by the waves; or, in another place, we find the strata made up of regular layers of sand and clay alternating, such as form from the gradual settling of the muddy material emptied into the ocean by rivers,—or, in another place, layers of rounded, water-worn pebbles, such as occur beneath rapidly-moving waters, whether of waves or rivers. We remark that these hard rocks differ from the loose sand, clay, or pebbly deposits simply in being consolidated into a rock. Then, in other places, we discover these sand-deposits in all states of consolidation, from the soft, movable sand, through a half-compacted condition, to the gritty sandstone; and, further, we discover, perhaps, the very means of this consolidation, and see it in its progress, making rock out of sand or clay. By such steps as these the mind is borne along irresistibly to the conclusion that rocks were slowly made through commonplace operations.

We may see, on another sea-shore, extensive beds of limestone forming from shells and corals, having as firm a texture as any marble; we may watch the process of accumulation from the growth of corals and the wear of the waves, and find the remains of corals and shells in the compact bed. If we then meet with a limestone over the continent containing remains of corals, or shells, no firmer, not different in composition, but every way like the coral reef-rock, or the shell-rock of other regions, the mind, if allowed to act at all, will infer that the ancient limestone was as much a slowly-formed rock, made of corals, or shells, as the limestone of coral seas.

In a volcanic district, we witness the melted rock poured out in wide-spread layers and cooling into compact rock, and learn, after a little observation, that just such layers piled upon one another make the great volcanic mountain, although it may be 10,000 feet in height. We remark, further, that the fractured crust in those regions has often let out the lava to spread the surface with rock, even to great distances from the crater.

Should we, after this, discover essentially the same kind of rock in wide-spread beds, and trace out the fractures filled with it, leading downward through the subjacent strata, as if to some seat of fires, and discover marks of fire in the baking of the underlying beds, we use our reason in the only legitimate way when we conclude that *these* beds were thrown out melted, even though they may be far from any volcanic centre.

If we see skeletons buried in sand and clay that we do not doubt are real skeletons of familiar animals, and then in a bed of rock discover other skeletons, but of unfamiliar animals, yet with every bone a true bone in form, texture, and composition, and every joint and limb modelled according to the plan in known species, we pass, by an unavoidable step, to the belief that the last is a relic of an animal as well as the former, and that it lies in its burial-place, although that burial-place be now the solid rock.

These few examples elucidate the mode of reasoning upon which geological deductions are based.

9. In using the present in order to reveal the past, we assume that the forces in the world are essentially the same through all time; for these forces are based on the very nature of matter, and could not have changed. The ocean has always had its waves, and those waves have ever acted in the same manner. Running water on the land has ever had the same power of wear and transportation and mathematical value to its force. The laws of chemistry, heat, electricity, and mechanics have been the same through time. The plan of living structures has been fundamentally one, for the whole series belongs to one system, as much almost as the parts of an animal to the one body; and the relations of life to light and heat, and to the atmosphere, have ever been the same as now.

The laws of the existing world, if perfectly known, are, consequently, a key to the past history. But this perfect knowledge implies a complete comprehension of nature in all her departments,—the departments of chemistry, physics, mechanics, physical geography, and each of the natural sciences. Thus furnished, we may scan the rocks with reference to the past ages, and feel confident that the truth will declare itself to the truth-loving mind.

As this extensive range of learning is not within the grasp of a single person, special departments have been carried forward by different individuals, each in his own line of research; for Geology as it stands is the combined result of the labors of many workers. But the system is now so far perfected that the ordinary mind may readily understand the great principles of the science, and comprehend the unity of plan in the earth's genesis.

SUBDIVISIONS OF GEOLOGY.

10. (1.) Like a plant or animal, the earth has its *systematic external form and features*, which should be reviewed.

(2.) Next, there are the *constituents of the structure* to be considered:—first, their *nature*; secondly, their *general arrangement*.

(3.) Next, the successive stages in the formation of the structure, and the concurrent steps in the progress of life, through past time.

(4.) Next, the general plan or laws of progress in the earth and its life.

(5.) Finally, there are the active forces and mechanical agencies which were the means of physical progress,—spreading out and consolidating strata, raising mountains, ejecting lavas, wearing out valleys, bearing the material of the heights to the plains and oceans, enlarging the oceans, destroying life, and performing an efficient part in evolving the earth's structures and features.

These topics lead to the following subdivisions of the science:—

I. Physiographic Geology,—a general survey of the earth's surface-features.

II. Lithological Geology,—a description of the rock-material of the globe, its elements, rocks, and arrangement.

III. Historical Geology,—an account of the rocks in the order of their formation and the contemporaneous events in geological history, including both stratigraphical and palæontological geology; and closing with a review of the system or laws of progress in the globe and its kingdoms of life.

IV. Dynamical Geology,—an account of the agencies or forces that have produced geological changes, and of the laws and methods of their action.

PART I.

PHYSIOGRAPHIC GEOLOGY.

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11. The systematic arrangement in the earth's features is every way as marked as that of any organic species; and this system over the exterior is an expression of the laws of structure beneath. The oceanic depressions or basins, with their ranges of islands, and the continental plains and elevations, all in orderly plan, are the ultimate results of the whole line of progress of the earth; and, by their very comprehensiveness as the earth's great feature-marks, they indicate the profoundest and most comprehensive movements in the forming sphere, just as the exterior configuration of an animal indicates its interior history. This subject is therefore an important one to the geologist, although its facts come also within the domain of physical geography. They lie at the top in geology as its last results, and, thus situated, they constitute necessarily the arena of the physical geographer.

The following are the divisions in this department:—

1. The earth's general contour and surface-subdivisions.
2. System in the reliefs or surface-forms of the continental lands.
3. System in the courses of the earth's feature-lines.

These topics are followed by a brief review of,—

4. The system of oceanic movements and temperature.
5. The system of atmospheric movements and temperature.
6. The general law for the distribution of forest-regions, prairies, and deserts.

1. THE EARTH'S GENERAL CONTOUR AND SURFACE-SUBDIVISIONS.

12. The subjects under this head are—the earth's form; the distribution of land and water; the depth and true outlines of the

oceanic depression; the subdivision of the land into continents; the height and kinds of surface of the continents.

13. (1.) **Spheroidal form.**—The earth has the form of a sphere with flattened poles, the distance from the centre to the pole being about 1-300th (accurately, $\frac{1}{299.2}$) shorter than from the centre to the equator. The earth's equatorial radius being 3963 miles, the polar is about 13¼ miles less (exactly 13.2465 miles).

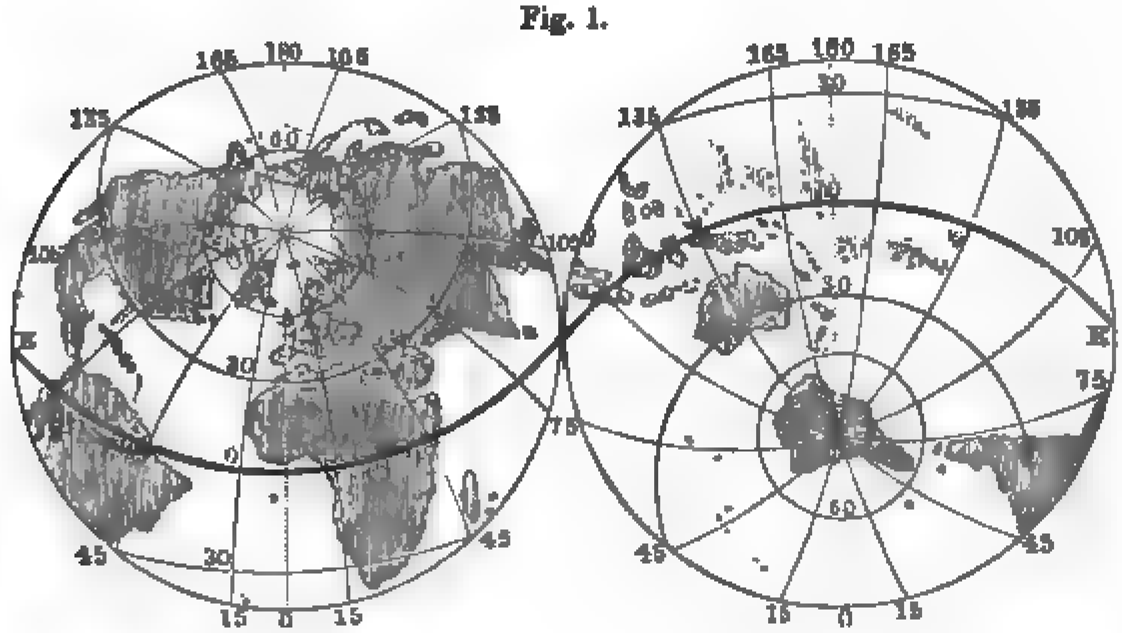
This is a fact of prime importance in geology, and an appropriate introduction to the science, inasmuch as it is the most obvious proof that the earth has a history, or has been in course of progress under secondary causes; for this flattening is in amount just that which the revolution at its actual rate would produce in a liquid globe having the size and density of the earth.

14. (2.) **General subdivisions of the surface.**—*Proportion of Land and Water.*—In the surface of the sphere there are about 8 parts of water to 3 of dry land, or, more exactly, 275 to 100 = $5^2 : 3^2$. The proportion of land north of the equator is nearly *three times* as great as that south. The zone containing the largest proportion of land is the north-temperate, the area equalling that of the water; while it is only one-third that of the water in the torrid zone, and hardly one-tenth (2–21ths) in the south-temperate.

Out of the 197,000,000 of square miles which make up the entire surface of the globe, 144,500,000 are water, and 52,500,000 land. In the northern hemisphere the land covers 38,900,000 square miles, in the southern 13,600,000 square miles.

15. *Land in one hemisphere.*—If a globe be cut through the centre by a plane intersecting the meridian of 175° E. at the parallel of 40° N., one of the hemispheres thus made, the northern, will

Fig. 1.



contain nearly all the land of the globe, and the other be almost wholly water. The annexed map represents the two hemispheres.

The pole of the land-hemisphere in this map is in the western half of the British Channel; and if this part, on a common globe, be placed in the zenith, under the brass meridian, the horizon-circle will then mark the line of division between the two hemispheres. The portions of land in the water-hemisphere are the extremity of South America below 25° S., and Australia, together with the islands of the East Indies, Pacific, and the Antarctic. London and Paris are situated very near the centre of the land-hemisphere.

16. *General arrangement of the Oceans and Continents.**—Oceans and continents are the grander divisions of the earth's surface. But, while the continents are separate areas, the oceans occupy one continuous basin or channel. The waters surround the *Antarctic* and stretch *north* in three prolongations,—the Atlantic, the Pacific, and the Indian Oceans. The land is gathered about the *Arctic*, and reaches *south* in two great continental masses, the occidental and oriental; but the latter, through Africa and Australia, has two southern prolongations, making in all three, corresponding to the three oceans. Thus the continents and oceans interlock, the former narrowing southward, the latter northward.

The Atlantic is the narrow ocean, its average breadth being 2800 miles. The Pacific is the broad ocean, being 6000 miles across, or more than twice the breadth of the Atlantic. The occident, or America, is the narrow continent, about 2200 miles in average breadth; the orient, the broad continent, 6000 miles. Each continent has, therefore, as regards size, its representative ocean. This great difference of magnitude is an important fact in its bearing on the earth's geological history. The Pacific Ocean, reckoning only to 62° S., has an area of 62,000,000 square miles, or nine and a half millions beyond the area of all the continents and islands.

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* In illustration of this part of the work, the reader is referred to the map at the close of the volume. It is a Mercator's chart of the world, which, while it exaggerates the polar regions, has the great advantage of giving correctly all courses, that is, the bearings of places and coasts. The trends of lines ("trend" means merely course or bearing) admit, therefore, of direct comparison upon such a chart. It is important in addition that the globe should be carefully studied in connection, in order to correct misapprehensions as to distances in the higher latitudes, and appreciate the convergences between lines that have the same compass-course.

The low lands of the continents on this chart, or those below 800 feet in elevation above the sea, are distinguished from the higher lands and plateaus by a lighter shading, and the axes of the mountain-ranges are indicated by black lines. The oceans are crossed by isothermal lines, which are explained beyond.

17. (3.) **Oceanic depression.**—(*a.*) *Outline.*—The oceanic depression is a vast sunken area, varying in depth from 1000 or less to, probably, 50,000 feet.

The true outline of the depression is not necessarily identical with the present line of coast. About the continents there is often a region of shallow depths which is only the submerged border of the continent. On the North American coast off New Jersey this submerged border extends out for 80 miles, with a depth, at this distance, of only 600 feet; and from this line the ocean-basin dips off at a steep angle. The true outline of the basin on this and other coasts is shown by the dotted line on the chart. The slope for the 80 miles is only 1 foot in 700.

Great Britain is, on the same principle, a part of the European continent: the separating waters are under 600 feet in depth; and a large part of the German Ocean is only 93 feet. The true oceanic outline extends from Southern Norway around by the north of Scotland and southward into the Bay of Biscay. (See the dotted line on the chart.) In a similar manner, the East India Islands, down to a line running by the north of New Guinea and Timor, are a part of Asia, the depth of the seas intermediate seldom exceeding 300 feet; while south of the line mentioned the islands are but fragments of Australia, the water being no deeper than over the submerged Asiatic plateau.*

(*b.*) *Depth of the Ocean.*—The depth of the ocean in its different parts has not been ascertained. Some deep soundings have been made, and a few of them claim to have reached to a depth of twenty-five to forty-five thousand feet; but the methods of sounding employed have been shown to be unsatisfactory, and the results, therefore, are valueless.† Across from Ireland to Newfoundland, the depth has been found to vary between 10,000 and 15,000 feet. The Gulf of Mexico is known to be from 4000 to 5000 feet in depth. According to calculations on the data furnished by an earthquake-wave which, in 1855, crossed from Simoda, in Japan, to San Francisco, the ocean in that line has an average depth of about 13,000 feet. The depth in the northern part of the Pacific and Atlantic may be, therefore, nearly the same. South of this in each it is probably very much greater.

The mean depth of the oceanic depression is, by estimate, between 15,000 and 20,000 feet.

(*c.*) *Character of the Oceanic Basins.*—To appreciate the oceanic basins

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* Earl, Jour. Indian Arch. [2], ii. 278, and Am. Jour. Sci. [2], xxv. 442.

† Some of the results are as follow: — A sounding by Capt. Ross, 900 m. S.W. of St. Helena, 27,600 feet without bottom; by Capt. Denham, in 36° 49′ S., 37° 6′ W., 46,236 feet (7706 fathoms) found bottom.

we must conceive of the earth without its water,—the depressed areas, thousands of miles across, sunk ten to perhaps fifty thousand feet below the bordering continental regions, and covering five-eighths of the whole surface. The continents, in such a condition, would stand as elevated plateaus encircled by one great uneven basin. If the earth had been left thus with but shallow lakes about the bottom, there would have been an ascent of five miles or more from the Atlantic vale to the lower part of the continental plateau, and one to five miles beyond this to scale the summits of the loftier mountains of the globe. The continents would have been wholly in the regions of the upper cold, all alpine and barren. This uneven surface of the Atlantic and Pacific has been levelled off to a plain by the waters of the ocean, the heights of the world reduced from ten or fifteen miles to five, and the intolerable climates of such extremes of surface reduced to a genial condition, rendering nearly the whole land habitable, and giving moisture for clouds, rivers, and plants; and, by the same means, distant points have been bound together by a common highway into one arena of history.

18. (4.) **General view of the land.**—(*a.*) *Position of the land.*—The land of the globe has been stated to lie with its mass to the north, about the Arctic, and to narrow as it extends southward into the waters of the Southern hemisphere. The mean southern limit of the continental lands is the parallel of 45°, or just half-way from the equator to the south pole.

South America reaches only to 56° S. (Cape Horn being in 55° 58′), which is the latitude of Edinburgh or northern Labrador; Africa to 34° 51′ (Cape of Good Hope), nearly the latitude of the southern boundary of Tennessee, and 60 miles nearer the equator than Gibraltar; Tasmania (Van Diemen's Land) to 43½° S., nearly the latitude of Boston and northern Portugal.

19. (*b.*) *Distribution.*—The independent continental areas are three in number:—America, one; Europe, Asia, and Africa, a second; Australia, the third. Through the East India Islands Australia is approximately connected with Asia, nearly as South America with North America through the West Indies; and, regarding it as thus united, the great masses of land will be but two:—The American, or *Occidental*, and Europe, Asia, Africa, and Australia, or the *Oriental*.

These great masses of land are divided across from east to west by seas or archipelagoes. The West Indies, Mediterranean, Red Sea, and the East Indies, with the connecting oceans, make a nearly complete band of water around the globe, as Professor Guyot observes, subdividing the Occident and Orient into north and south divisions. Cutting across 37 miles at the Straits of Darien, where

at the lowest pass the greatest height above mean tide-level does not exceed 506 feet, and through 70 miles at the Isthmus of Suez, where the summit-level is only 40 feet above the sea, the girth of water would be unbroken.

America is thus divided into North and South America. The oriental lands have one great area on the north, comprising Europe and Asia combined, and on the south (1) Africa, separated from Europe by the Mediterranean, and (2) Australia, separated from Asia by the East India seas. Thus the narrow Occident has one southern prolongation, and the wide Orient two. It is to be noted that the East and West Indies are very similar in form and position (see chart); and also that South America is situated with reference to North America very nearly as Australia is to Asia.

The Orient thus corresponds to two Occidents in which the northern areas coalesce,—Europe and Africa one, Asia and Australia the other; so that there are really three doublets in the system of continental lands. Moreover, Europe and Asia have a semi-marine region between them; for the Caspian and Aral are salt seas, and they lie in a depression of the continent of great extent,—the Aral being near the level of the ocean, and the Caspian 80 to 100 feet below it.

The islands adjoining the continents are properly portions of the continental regions. Besides the examples mentioned on page 12, Japan and the ranges of islands of eastern Asia are strictly a part of Asia, for they conform in direction to the Asiatic system of heights, and are united to the main by shallow waters. Vancouver's Island and others north are similarly a part of North America; Chiloe, and the islands south to Cape Horn, a part of South America; and so in other cases.

The body of the continent of Africa lies in those latitudes which are almost wholly water in the American section, its eastern expansion corresponding to the indentation of the Caribbean Sea and the Gulf of Mexico.

20. (*c.*) *Oceanic islands.*—The islands of mid-ocean are in ranges, and are properly the summits of submerged mountain-chains. The Atlantic and Indian Oceans are mostly free from them. The Pacific contains about 675, which have, however, an aggregate area of only 80,000 square miles. Excluding New Caledonia and some other large islands in its southeastern part, the remaining 600 islands have an area of but 40,000 square miles, or less than that of New York State. The islands stretch off in a train from the Asiatic coast through the tropics in a west-southwest direction, and, soon crossing the equator, lie mostly in the southern tropic. The train

extends to Easter Island and Sala-y-Gomez, in longitudes 110° and 105° W., a distance of 8000 miles. The greatest depth of the ocean should be looked for outside of the limits of this train.

21. (*d.*) *Mean elevation.*—The mean height of the continents above the sea, exclusive of Australia and Africa, according to an estimate by Humboldt, is about 1000 feet; and this is probably not far from the truth for all the land of the globe. As the area of the ocean and land is as 8 to 3, if all this land above the present water-level were transferred into the oceans, it would fill them 3-8ths of 1000 or 375 feet; and, taking the average depth at 15,000 feet, it would take 40 times this amount to fill the oceanic depressions. Moreover, increasing the average depth of the oceanic basin 375 feet would expose approximately 1000 feet in height of land, as it would draw off the water corresponding to this result.

The mean height of the several continents has been stated as follows:—Europe, 670 feet; Asia, 1150; North America, 748; South America, 1132; all America, 930; Europe and Asia, 1010; Africa, probably about 1600 feet; and Australia, perhaps 500. It has been estimated that the material of the Pyrenees spread over Europe would raise the surface only 6 feet; and the Alps, though four times larger in area, only 22 feet.

The extremes of level in the land, as far as now known, are, 1300 feet *below* the level of the ocean, at the Dead Sea, and 29,000 feet *above* it, in Mount Everest of the Himalayas.

22. (5.) **Subdivisions of the surface, and character of its reliefs.**—The surfaces of continents are conveniently divided into (1) low lands; (2) plateaus, or elevated table-lands; (3) mountains. The limits between these subdivisions are quite indefinite, and are to be determined from a general survey of a country rather than from any specific definition.

The *low lands* include the extended plains or country lying not far above tide-level. In general they are less than 1000 feet above the sea; but they are marked off rather by their contrast with higher lands of the mountain-regions than by any precise altitude. The Mississippi Valley of the great interior region of the North American continent is an example; also the plains of the Amazon; the pampas of La Plata; the lower lands of Europe and Asia. The surface is usually undulating, and often hilly. Frequently the surface rises so gradually into the bordering mountain-declivities that the limit is altogether an arbitrary line, as in the case of the Mississippi plains and the Rocky Mountain slope.

A *mountain* is either an isolated peak,—as Mount Washington, Mount Blanc, Mount Etna,—or a ridge. For a long ridge or range,

the plural is used, as the Green *Mountains*, the Ozark *Mountains*. A *mountain-chain* is a system of ridges with the included high land.

A *sierra* is, in Spanish, a ridge of mountains, and alludes to the saw-like outline. A *cordillera*, in South America, is a mountain-chain. *Mauna*, as in Mauna Loa, of Hawaii, signifies *mount*.

An *elevated plateau* is an extensive elevated region of flat or hilly surface, such as often occurs in mountainous regions. Any extensive range of country that is over a thousand feet in altitude would be called a plateau. It may lie along the course of a mountain-chain, or occupy a wide region between distant chains. The "Great Basin" between the Salt Lake and the Sierra Nevada is a plateau of the Rocky Mountain chain, 4000 to 5000 feet in elevation: the Salt Lake lies in its northeast corner, 4200 feet above the sea. The plateau or table-land of Thibet lies between the Himalayas and the Kuen-Luen Mountains next to the north, and is 11,500 to 13,000 feet in altitude; and the plateau of Mongolia (Desert of Gobi) occupies a vast region farther north, having a mean elevation of 4000 feet. The State of New York is an elevated plateau, 1500 to 1700 feet in altitude north of the Mohawk (an east-and-west valley), and 2000 to 2500 feet south of this river: it lies in the course of the Appalachian Mountains.

Plateaus often have their mountain-ridges, like low lands.

23. Mountains.—The *form* of an *isolated mountain*-peak depends on its general slopes; that of a *ridge*, on (1) its slopes, (2) the outline of the crest, and (3) the course or arrangement of the consecutive parts of the ridge; that of a *chain*, on all these points, and in addition (4) the order or arrangement of the ridges in the chain.

(*a.*) *Slopes of mountains.—The mountain-mass.*—The slopes of the larger mountains and mountain-chains are generally very gradual. Some of the largest volcanoes of the globe, as Etna and Mount Loa (Hawaii), have a slope of only 6 to 8 degrees. The mountains are low cones having a base of 50 miles or more.

The Rocky Mountains, Andes, and Appalachians are three examples of mountain-chains. The average eastern slope of the Rocky Mountains seldom exceeds 10 feet in a mile, which is about 1 foot in 500, equal to an angle of only 7 minutes. On the west the average slope is but little less gradual. The rise on the east continues for 600 miles, and the fall on the other side for 400 to 500 miles; the passes at the summit have a height of 6000 to 10,000 feet; and above them, as well as over different parts of the slopes (especially on the west), there are ridges carrying the altitude to 12,000 or 14,000 feet. The mountain-mass, therefore, is not a narrow barrier between the east and west, as might be inferred from

the ordinary maps, but a vast yet gentle swell of the surface, having a base 1000 miles in breadth, and the slopes diversified with various mountain-ridges or spreading out in plateaus at different levels.

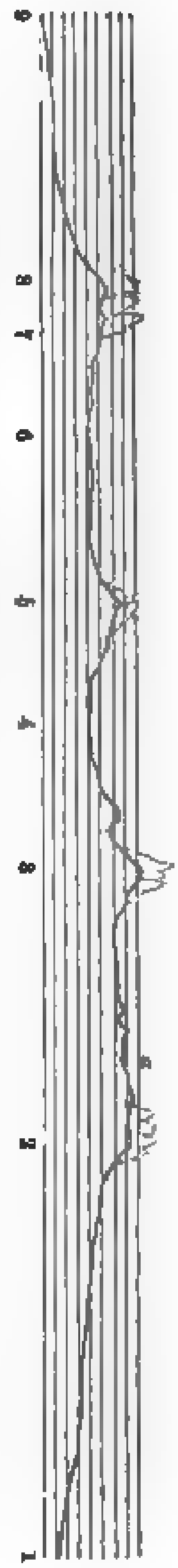
The annexed section (Fig. 2) of the Rocky Mountains along the parallels 41° and 42°, from Council Bluff, on the east, to Benicia, in California, illustrates this feature, although an exaggerated representation of the slopes,—the height being *seventy times* too great for the length.

In the Andes the eastern slope is about 60 feet in a mile, and the western 100 to 150 feet; the passes are at heights from 12,500 to 16,160 feet, and the highest peak—Sorata in Bolivia—25,290 feet. The slope is much more rapid than in the Rocky Mountains. But there is the same kind of mountain-mass variously diversified with ridges and plateaus. The existence of the great mountain-mass and its plateaus is directly connected with the existence of the main ridges. But it will be shown in another place that the ridges may have existed long before the mass had its present elevation above the sea.

In the Appalachians—which include all the mountains from Georgia to the Gulf of St. Lawrence—the mountain-mass is very much smaller and the component ridges are relatively more distinct and numerous, and still the general features are on the same principle. The greatest heights—those of North Carolina—are between 6000 and 6800 feet.

The Rocky Mountains, Andes, and Appalachians represent the three types of chains: (1) the broad and lofty plateau type; (2) the narrow and lofty ridgy type, of which the Himalayas are another example; (3) the broad and many-folded type, of which the Juras are another example.

Fig. 2.



Section of Rocky Mountains along the 41st and 42d parallel.—*Beckwith.* 1, Council Bluff, 41° 30′ N., 96° 01′ W., 1327 feet above the sea; 2, Cheyenne Pass, 41° 17′ N., 105° 20′ W. 7800 feet; 4, Laramie Plains, 7000 feet; 3, Divide between Black and Muddy Creeks, 8373 feet; 4, Salt Lake Basin, 4238 feet; 5, Humboldt mountain-pass; 6, Great Basin, 4100 to 4600 feet; 7, 8, Sierra Nevada (7, Madelin Pass, 5667 feet; 8, 5736 feet); 9, Benicia, on the Pacific.

ILLUSTRATIONS.—It is common to err in estimating the angle of a slope. To the eyes of most travellers, a

slope of 60° appears to be as steep as 80°, and one of 30° to be at least 50°. In a front view of a declivity it is not possible to judge rightly. A profile view should always be obtained and carefully observed before registering an opinion.

Fig. 3.

In fig. 3 the bluff front facing the left would be ordinarily called a vertical precipice, while its angle of slope is actually about 65°; and the talus of broken stones at its base would seem at first sight to be 60°, when really 40°.

Fig. 4.

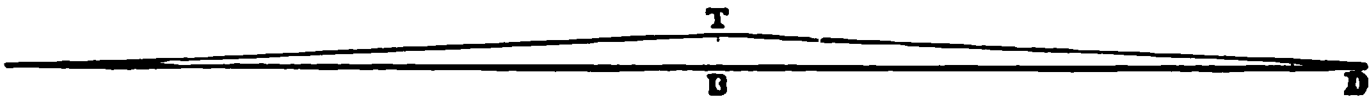


Fig. 5.

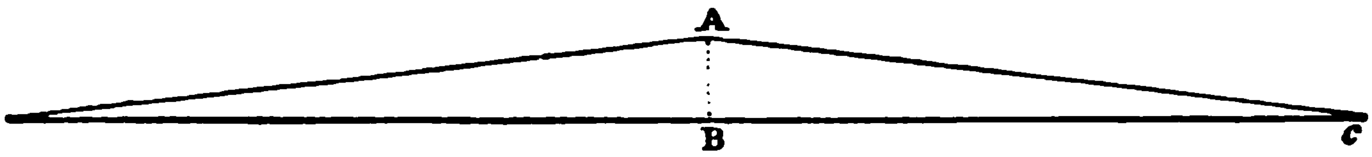


Fig. 6.

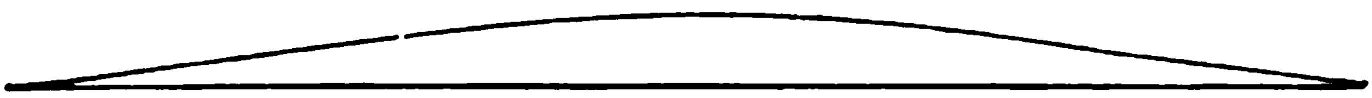
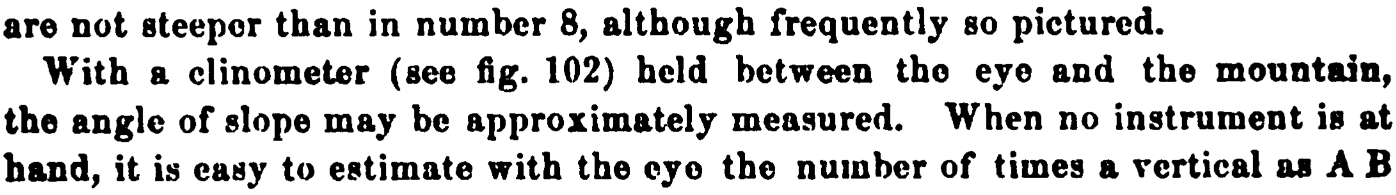


Fig. 4 represents a section of a volcanic mountain 3° in angle; 5, another, of 7°,—the average slope and form of Mount Kea, Hawaii; 6, the same slope with

Fig. 7. Fig. 8. Fig. 9.

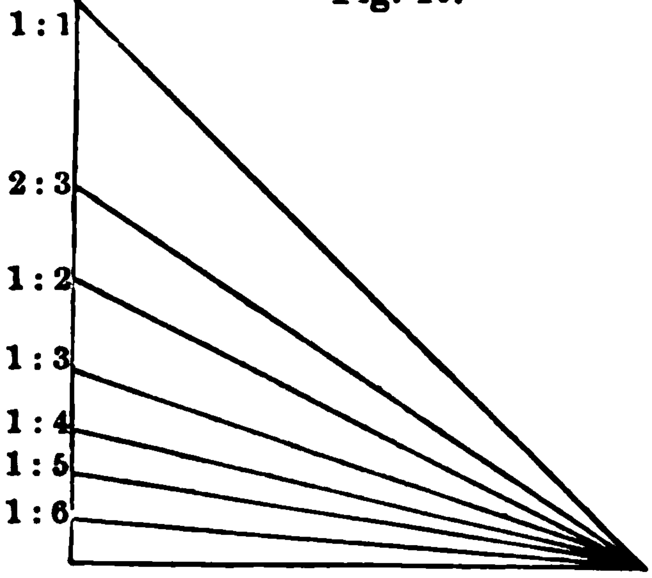


the top rounded, as in Mount Loa; 7, a slope of 15°; 8, Jorullo, in Mexico, which has one side 27° and the other 34°, as measured by N. S. Manross; 9, a slope of 40°,—the steepest of volcanic cones. The lofty volcanoes of the Andes are not steeper than in number 8, although frequently so pictured.

With a clinometer (see fig. 102) held between the eye and the mountain, the angle of slope may be approximately measured. When no instrument is at hand, it is easy to estimate with the eye the number of times a vertical as A B in fig. 5 is contained in the semi-base B C; and, this being ascertained, the angle of slope may be easily calculated. The ratio 1 : 1 corresponds to the angle of 45°; 1 : 2 to 33° 41½′; 1 : 3 to 26° 34′; 1 : 4 to 18° 26′; 1 : 5 to 11° 18½′; 1 : 6 to 9° 28′; 1 : 7 to 8° 8′; 1 : 8 to 7° 7½′; 1 : 9 to 6° 20½′; 1 : 10 to 5° 42½′; 1 : 12 to 4° 46′; 1 : 15 to 3° 49′; 1 : 20 to 2° 52′. The inclinations corresponding to several of these ratios are represented in the following cut. Fig. 10.

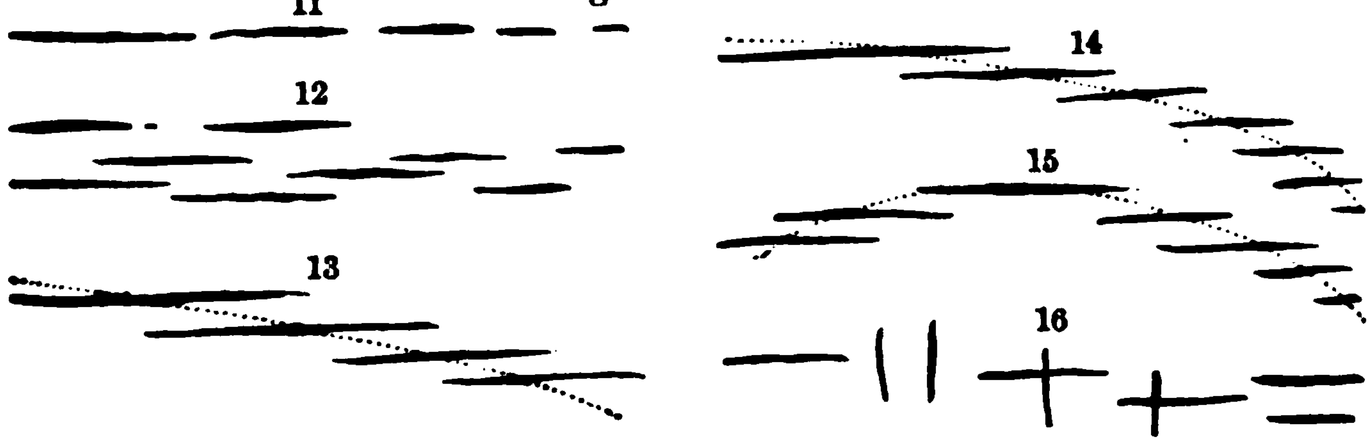
24. (*b.*) *Composition of mountain-chains.*—(1.) Mountain-chains have been stated to include several mountain-ridges; and even the ridges often consist of subordinate parts similar in arrangement. In the great chain of western North America,—the Rocky Mountains,—about the summit there are, in general, two prominent ranges; then, west of the summit, within 100 to 150 miles of the coast, there is the Washington Range, including the Cascade of Oregon and the Sierra Nevada of California, each with peaks over 12,000 feet in height; between this range and the summit there are in many parts several ridges more or less important; and between it and the coast other ridges make up what has been called the Coast Range. The Appalachians also, although but a small chain, consist of a series of nearly parallel ridges. In Virginia there are, beginning to the eastward, the Blue Ridge, the Shenandoah Ridge, and the Alleghany, besides others intermediate.

Fig. 10.



(2.) The ridges of a chain vary along its course. After continuing for a distance, they may gradually become lower and disappear; and while one is disappearing another may rise to the right or left; or the mountain may for scores of leagues be only a plateau without a high ridge, and then new ranges of elevations appear. The Rocky Mountains exemplify well this common characteristic, as is seen on any of the recent maps. The Sierra Nevada dies out where the Cascade Range begins; and each has minor examples of the same principle. The Andes are like the Rocky Mountains; only the parts are pressed into narrower com-

Figs. 11 to 16.

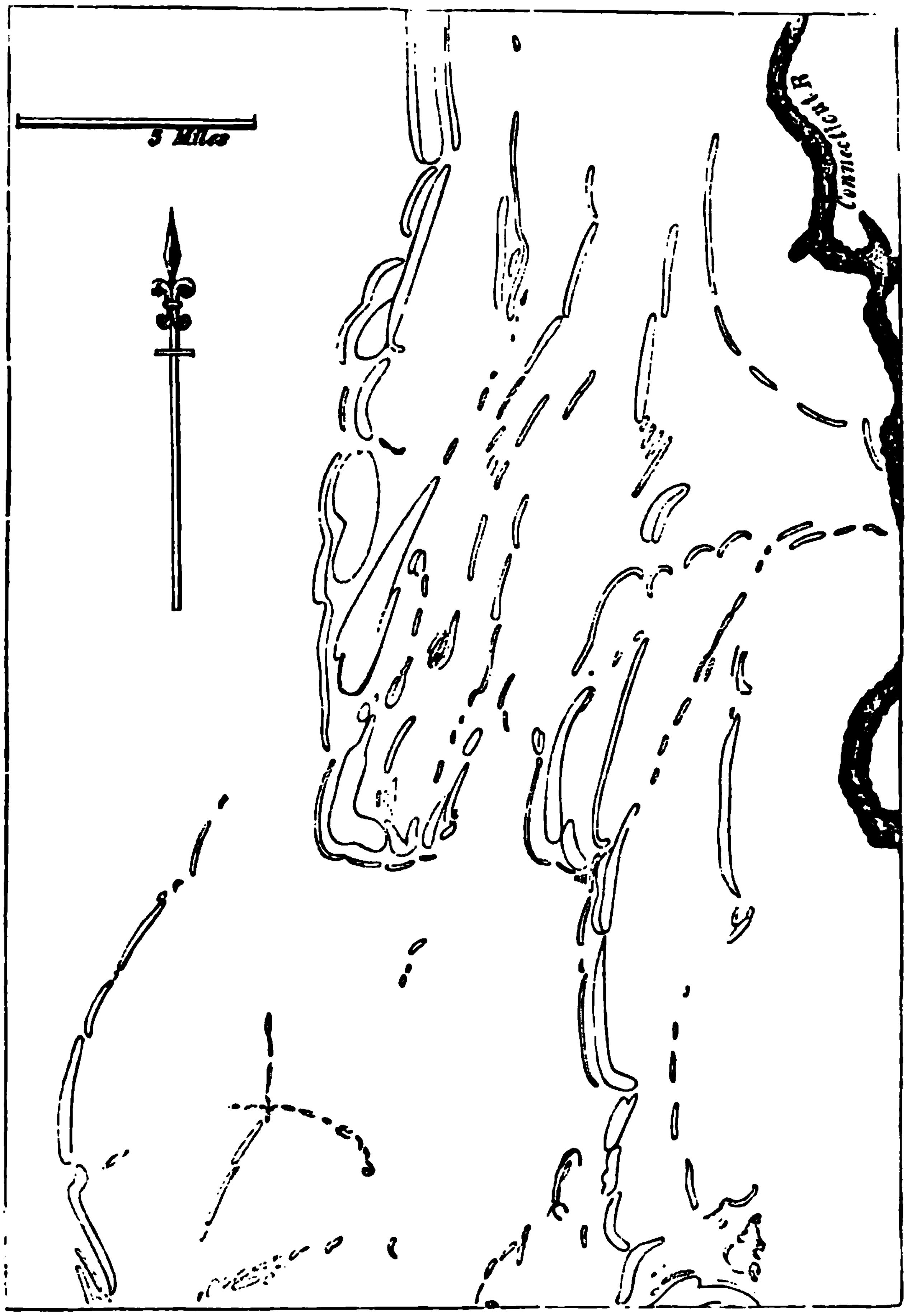


pass, and the crest-ranges are hence continuous for longer distances. The Appalachian ridges are rising and sinking along the

course of the chain. The high land of the southwest terminates in New York; and just east stands the separate line of the Green Mountains; and still farther eastward,—east of the Connecticut,—the range of the White Mountains.

The general idea of this composite structure is shown in figs.

Fig. 17.



11 to 16, where each series of lines represents a series of ridges in a composite range. In fig. 11 the series is simple and straight;

in 12 it is still straight, but complex; in 13 the parallel parts are so arranged as still to make a straight composite range; while in 14 and 15 the succession forms a curve; and in 16 there are transverse ridges in a complex series. In ridges or ranges thus compounded, the component parts may lie distinct, or they may so coalesce as not to be apparent.

These several conditions of uninterrupted and overlapping lines, constituting straight and curving chains, are illustrated among the islands of the oceans, the direction of coast-lines, and the courses of all the reliefs of the earth's surface, as is explained in the following pages. Figure 28 on page 35, representing the positions of the Australasian islands from New Hebrides to Sumatra, finely exhibits the system of structure,—also fig. 27, giving the courses and relative positions of the central groups of the Pacific, and fig. 29, representing the Azores in the Atlantic; for the courses of islands are the courses of mountain-chains. The South Atlantic and North Atlantic are two overlapping lines parallel in course, and on a still grander scale, one of them being much in advance or to the westward of the other, and each several thousand miles long.

The preceding map of the trap ridges of Connecticut, from Percival's Report, presents the structure finely. The narrow bands running nearly north-and-south represent the ridges; they are in many nearly parallel lines; each consists of subordinate parts; and in several the parts lie in advancing or receding series. The extent of the series is small compared with a mountain-chain; and the ridges, few of which exceed 600 feet in height, are ejections through fissures beneath. But the parallelism in structure is perfect. The curves in some of the subordinate ridges have arisen from the fact that the fissures come up through a tilted sandstone, and the ejected rock escaped partly direct from the fissure and partly between the lifted strata of sandstone, and hence in a direction different from that of the fissure, the two directions together making the curve.

25. *Solid dimensions of mountains.*—The modes of calculating the mass of a mountain are the same that are given in treatises on mensuration. By a careful system of averaging, based on determinations of the slopes and altitudes, as far as practicable, the mountain-mass is reduced to one or more cones, pyramids, or prisms; and then the solid contents of the cones or pyramids are obtained by multiplying the area of the base into one-third the altitude; or, for a triangular prism lying on one of its sides, the area of that side into half the length of a line drawn vertical to it from the opposite edge.

26. Elevated Plateaus, or *table-lands.*—Some examples of these plateaus have been mentioned (§ 22). The Llano Estacado (staked plain) in New Mexico and Upper Texas, southeast of Santa Fé, is another, of great extent, about 4500 feet in elevation. The great Mexican plateau, in which the city of Mexico lies, has

about that city a height of 7482 feet, and slopes from this to 5000 on the east and 4000 on the west; and it stretches on north beyond the Mexican territory, blending with the plateaus of New Mexico. Above it rise many lofty volcanic cones, among which Popocatepetl is 17,884 feet high, Orizaba 17,373 feet, and Istaccihuatl 15,704.

The plateau of Quito, in the Andes, has a height of 10,000 feet,—Quito itself 9540 feet; and around it are Cotopaxi, 18,775 feet, Chimborazo, 21,421, Pichincha, 15,924, Cayambe, 19,535. The plateau of Bolivia is at an elevation of 12,900 feet, with Lake Titicaca, 12,830 feet, and the city of Potosi at 13,330 feet: and near are the volcanic peaks Illimani, 23,868 feet, Sorata, 25,290, Huayna Potosi, 20,260. In Europe, Spain is for the most part a plateau about 2250 feet in average elevation; Auvergne, in France, another, at about 1100 feet; Bavaria another, at 1660 feet. Persia is a plateau varying in elevation between 3800 and 4500 feet, with high ridges in many parts. The Abyssinian plateau, in Africa, has an average elevation of more than 7000 feet; the region of Sahara, about 1500; that of the interior of Africa south of the equator, about 2500 feet.

27. River-Systems.—Plateaus and mountains are the sources of rivers. They pour the waters along many channels into the basin or low country towards which they slope; and the channels, as they continue on, unite into larger channels, and finally into one or more trunks which bear the waters to the sea. The basin and its surrounding slopes make up a river-system. The extent of such a region will vary with the position of the mountains and ocean. It may cover but a few hundred square miles, like the river-regions on a mountainous coast, or it may stretch over the larger part of a continent.

The interior of the United States belongs to one river-system,—that of the Mississippi; its tributary streams rise on the west among the snows of the Rocky Mountains, on the north in the central plateau of the continent, west of Lake Superior, near lat. 47° and beyond long. 93°–96°, 1680 feet in elevation, and on the east in the Appalachians, from western New York to Alabama. Besides the Mississippi, there are other rivers rising in the Rocky Mountains and flowing into the Gulf of Mexico; and, in a comprehensive view of the continent, these belong to the same great river-system.

The St. Lawrence represents another great river-region in North America,—a region which commences in the head-waters of Lake Superior about the same central plateau of the continent that gives rise to the Mississippi, and embraces the great lakes with their tributaries and the rivers of Canada, and flows finally northeastward into the Atlantic, following thus a northeast slope of the continent. North of Lake Superior and the head-waters of the Mississippi, as far as the parallel of 55°, there are other streams,

which also flow northeastward, deriving some waters from the Rocky Mountains through the Saskatchewan, and reaching the ocean through Hudson's Bay. Winnipeg Lake is here included. These belong with the St. Lawrence, the whole together constituting a second continental river-system.

The Mackenzie is the central trunk of still another river-system, —the northern. Starting from near the parallel of 55°, it takes in the slopes of the Rocky Mountains adjoining, and much of the northern portion of the continent. Athabasca, Slave, and Bear Lakes lie in this district.

These are examples from among the river-systems of the world.

LAKES.—Lakes occupy depressions in the earth's surface which, from their depths or positions, are not completely drained by the existing streams, nor kept dry by the heat and drought of the climate. They occur (1) over the interior of table-lands, as about the head-waters of the Mississippi; (2) along the depressions between the great slopes of a continent, as the line of lakes in British North America running northwest from Lake Superior; (3) in confined areas among the ridges of mountains. The natural forms of continents—that is, their having high borders—tend to occasion the existence of lakes in their interior.

If a lake has no outlet to the ocean, its water is usually salt; and any plain or plateau whose streams dry up without communicating with the sea contains salt basins and efflorescences. The Caspian, Aral, and Dead Sea are some of the salt lakes of Asia; and the Great Salt Lake of the Rocky Mountains is a noted one on this continent. Many parts of the Rocky Mountains, the Great Basin of the West, the Pampas of South America, and all the desert regions of the globe, afford saline efflorescences.

2. SYSTEM IN THE RELIEFS OR SURFACE-FORMS OF THE CONTINENTS.

28. **Law of the system.**—The mountains, plateaus, low lands, and river-regions are the elements in the arrangement of which the system in the surface-form of the continents is exhibited. The law at the basis of the system depends on a relation between the continents and their bordering oceans, and is as follows:—

First. The continents have in general elevated mountain-borders and a low or basin-like interior.

Secondly. The highest border faces the larger ocean.

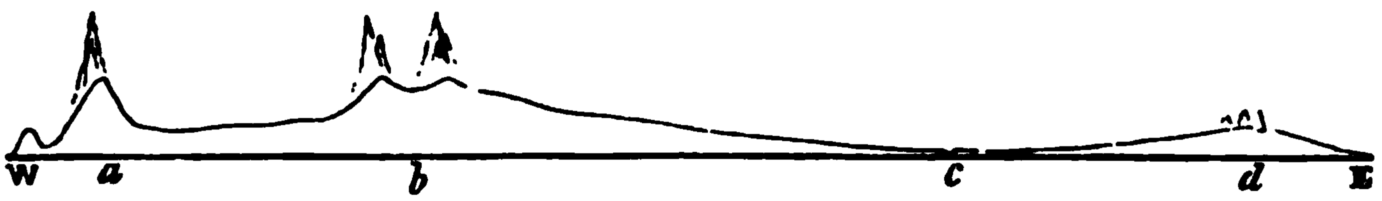
A survey of the continents in succession with reference to this law will exhibit both the unity of system among them and the

peculiarities of each dependent on their different relations to the oceans.

29. (1.) **America.**—The two Americas are alike in lying between the Atlantic and the Pacific: moreover, South America is set so far to the west of North America (being east of the meridian of Niagara Falls) that each has an almost entire ocean-contour. Moreover, each is triangular in outline, with the widest part, or head, to the north.

North America, in accordance with the law, has on the Pacific side—the side of the great ocean—the Rocky Mountains, on the Atlantic side the low Appalachians, and between the two there is the great plain of the interior. This is seen in the annexed section (fig. 18) from west to east: on the west, the Rocky Moun-

Fig. 18.



tains, with the double crest, at *b*, the Washington Range at *a*, between *a*, *b* the Great Basin, at *d* the Appalachians, *c* the Mississippi, and between *d* and *b* a section of the Mississippi river-system.

The Cascade and Nevada Ranges are even more lofty in some of their summits than the crest-ridges of the Rocky chain. In the former there is a line of snowy cones from 12,000 to 16,000 or 18,000 feet in elevation, including Mount Baker, near Puget's Sound, and, to the south of this, Mount St. Helen's, Mount Adams, and Mount Rainier, north of the Columbia, and, south, Mount Hood, Mount Pitt, Mount Jefferson, and the Shasta Peak,—the last on the border of California. Still nearer the sea there is what is called the Coast Range, consisting of lower elevations. Between the two lie the valley of the Sacramento and Joaquin, in California, and that of the Willamette, in Oregon.

The Appalachians, on the east, reach an extreme height of but 6700 feet, and are in general under 2500 feet.

To the north of North America lies the small Arctic Ocean, much encumbered with land; and, correspondingly, there is no distinct mountain-chain facing the ocean. The mountains of Greenland are an independent system, pertaining to that semi-continent by itself.

The characteristics of the interior plain of the continent are well displayed in its river-systems: the great Mississippi system turned to the south, and making its exit into the Gulf of Mexico between the approaching extremities of the eastern and western mountain-ranges; the St. Lawrence sloping off northeastward;

the Mackenzie, to the northward; the central area of the plain dividing the three systems being only about 1700 feet above the ocean,—a less elevation than about the head-waters of the Ohio in the State of New York.

South America, like North America, has its great western range of mountains, and its smaller eastern (fig. 19); and the Brazilian

Fig. 19.

line (*b*) is closely parallel to that of the Appalachians. As the Andes (*a*) face the South Pacific, a wider and probably much deeper ocean than the North Pacific, so they are more than twice the height of the Rocky Mountains, and, moreover, they rise more abruptly from the ocean, with narrow shore-plains.

Unlike North America, South America has a broad ocean on the north,—the North Atlantic in its longest diameter; and, accordingly, this northern coast has its mountain-chain reaching along through Venezuela and Guaiana.

The drainage of South America, as observed by Professor Guyot, is closely parallel with that of North America. There are, *first*, a southern,—the La Plata,—reaching the Atlantic towards the south, between the converging east-and-west chains, like the Mississippi; *second*, an eastern system,—that of the Amazon,—corresponding to the St. Lawrence, reaching the same ocean just north of the eastern mountain-border; and, *third*, a northern system,—that of the Orinoco,—draining the slopes or mountains north of the Amazon system. The two Americas are thus singularly alike in system of structure: they are built on one model.

The relation of the oceans to the mountain-borders is so exact that the rule-of-three form of statement cannot be far from the truth. *As the size of the Appalachians to the size of the Atlantic, so is the size of the Rocky chain to the size of the Pacific.* Also, *As the height of the Rocky chain to the extent of the North Pacific, so are the height and boldness of the Andes to the extent of the South Pacific.*

30. (2.) **Europe and Asia.**—The land covered by Europe and Asia is a single area or continent, only partially double in its nature (§ 19). Unlike either of the Americas, it lies east-and-west, with an extensive ocean facing Asia on the south; and its great feature-lines are in a large degree east-and-west. The Arctic is on the north; the North Atlantic is on the west; the North

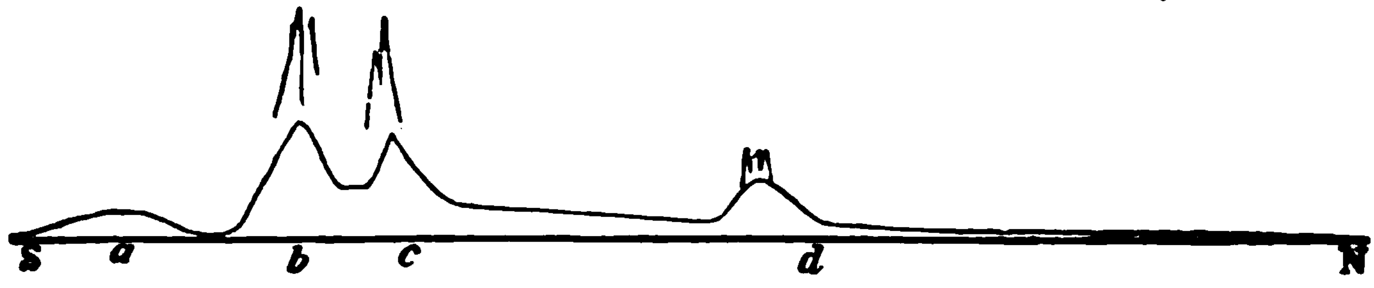
Pacific on the east; Africa and the Indian Ocean are on the south. The Atlantic is the smallest ocean; the North Pacific next,—for its average depth is probably not over 13,000 feet (p. 12), and it is much encumbered by islands to the west-of-south; the Indian Ocean next,—for it is full 5000 miles wide in front of the Asiatic coast, and singularly free from islands. The boundary is a complex one, and the land between the Atlantic and Pacific over 6000 miles broad.

On the side of the small North Atlantic there are the mountains of Norway and the British Isles, the former having a mean height of 4000 feet. On the Pacific side there are loftier mountains, extending in several ranges from the far north to southern China,—the Stanovoi, Jablonoi, and the Khingan Ranges; and off the coast there is still another series of ranges, now partly submerged,—viz., those of Japan and other linear groups of islands. These stand in front of the interior chain, very much as the Cascade Range and Sierra Nevada of the Pacific border of America are in advance of the summit-ridges of the Rocky Mountains, and both are alike in being partly volcanic, with cones of great altitude.

Facing the still greater Indian Ocean, and looking southward, stand the Himalayas,—the loftiest of mountains,—called the Himalayas as far as Cashmere, and from there, where a new sweep in the curve begins, the Hindoo Cush,—the whole over 2000 miles in length: not so long, it is true, as the Andes, but continued as far as the ocean in front continues. The mean height of the Himalayas has been estimated at 16,000 feet; over forty of the peaks surpass Chimborazo. The Kuen-Luen Mountains, to the north of the Himalayas, make another crest to the great chain, with Thibet between the two. Going westward, the mountains decline, though there are still ridges of great elevation.

On the north there are the great Siberian plains, backed by the Altai, about half the Himalayas in height. The Altai thus have

Fig. 20.



the same relation to the Himalayas as the Appalachians to the Rocky Mountains, or the Brazilian Mountains to the Andes, yet

with a striking difference in the immense shore-plain between them and the sea.

The sketch (fig. 20) presents the general features to the eye. At *a*, there is the elevated land of India; between *a* and *b*, the low river-plain at the base of the Himalayas; at *b*, the Himalayas; *b* to *c*, Plains of Thibet; *c*, the Kuen-Luen ridge; *c* to *d*, Plains of Mongolia and Desert of Gobi; at *d*, the Altai; *d* to N, the Siberian plains.

The interior region of the continent in its eastern half is the plateau of Gobi and Mongolia, which, at 4000 feet, is low compared with the mountains in front and rear. More to the westward the region *c*, *d* becomes intersected by the lofty Thian-chan Range. Still farther westward the surface declines into the great depression occupied by the Caspian and Aral, part of which is below tide-level (§ 19).

The interior drainage-system for Asia is without outlet. The waters are shut up within the great basin, the Caspian and Aral being the seas which receive those waters that are not lost in the plains. The Volga and other streams, from a region of a million of square miles, flow into the Caspian.

The Urals stand as a partial barrier between Asia and Europe, parallel nearly with the mountains of Norway.

Europe has its separate system of elevations and interior plains; but it is not necessary to dwell on it here.

The great continental mass accords with the law stated:—high borders proportioned in the case of each to the extent of the bordering oceans, and a general basin-form.

31. (3.) **Africa.**—Africa has the Atlantic on the west, the larger Indian Ocean on the east, with Europe and the Mediterranean on the north, and the South Atlantic and Southern Ocean on the south. Its system of structure has been well explained by Professor Guyot. As he has stated, the northern half has the east-and-west position of Asia, and the southern the north-and-south of America; and its reliefs correspond with this structure. The Guinea coast belonging to the northern half projects east in front of the South Atlantic, and is faced by the east-and-west Kong Range; and opposite, on the Mediterranean, there are the Atlas Mountains, one peak of which is 11,000 feet high,—although the ridges are generally much lower. The two thus oppose one another, like the Himalayas and Altai. The southern half of the continent has a border mountain-range the most of the way along the west and south. On the latter, which has a length of 700 miles, there are three or four parallel ridges, and some of the peaks are 4000 to 7000 feet high. Up the eastern coast there is

also a mountain-border, and higher than the western. By these border-ranges the interior of Africa is mostly shut off from the sea: —it is a *shut-up* continent, as Guyot calls it. The loftiest mountains are in Abyssinia and Zanguebar, facing the Indian Ocean. Abyssinia is, to a great extent, an elevated plateau, 6000 to 7000 feet in height, with ridges reaching to 11,000 and 13,500 feet; and farther south, in 3° 40′, stands the snowy Kilimanjaro, which, according to report, is 20,000 feet high, and probably the source of the Nile.

The interior of the *northern* or east-and-west half consists of (1) the Great Sahara region, a plateau of about 1500 feet elevation, with its undulations and ridges; (2) an east-and-west depression on the north, between Sahara and the border-mountains, nearly to the ocean's level in some parts, and being the region of the *oases;* (3) a partial east-and-west depression about the parallels 10° to 15° N., separating the Sahara plateau from the southern, and containing Lake Tchad, at an elevation of 800 feet. The interior of the *southern* half is a plateau 2000 to 2500 feet in average height: the great lake Uniamesi, south of the equator, between the meridians 25° and 35°, is stated by Livingstone to have its surface 2000 feet above the sea.

Fig. 21.

The sections figs. 21 and 22 give a general idea of these features Fig. 21 is a section from south to north (the heights necessarily much exaggerated in proportion to the length); *a*, the southern mountains; *b*, the southern plateau; *c*, Lake Tchad depression; *d*, Sahara plateau; *e*, oases depression; *f*, mountains on the Mediterranean, of which there are two or three parallel ranges. Fig. 22

Fig. 22.

represents the surface-outline from west to east through the southern half of the continent. In all these sections all minor details are omitted, in order to bring out clearly the system, or continental model.

Africa has, therefore, the basin-form, but is a double basin; and its highest mountains are on the side of the largest ocean, the Indian. The height of the mountains adjoining the Mediterranean is the only exception to the relation to the oceans; and this is small. Moreover, the position of the head of the continent

against the continent of Europe with only the Mediterranean between, instead of an ocean, is a sufficient reason for the exceptions. Africa has some resemblance to America, but America turned about, with the most elevated border on the east instead of the west.

32. (4.) **Australia.**—Australia conforms also to the continental model. The highest mountains are on the side of the Pacific,—the larger of its border-oceans. The Australian Alps, in New South Wales, facing the southwest shores, have peaks 5000 to 6500 feet in height. The range is continued northward in the Blue Mountains, which are 3000 to 4000 feet high, with some more elevated summits, and, beyond these, in ridges under other names, the whole range being mostly between 2000 and 6000 feet in elevation. The interior is regarded as a low, arid region.

The continents thus exemplify the law laid down, and not merely as to high borders around a depressed interior,—a principle stated by many geographers,—but also as to the highest border being on the side of the greatest ocean.* The continents, then, are all built on one model, and in their structures and origin have a relation to the oceans that is of fundamental importance.

It is owing to this law that America and Europe literally stand facing one another, and pouring their waters and the treasures of the soil into a common channel, the Atlantic. America has her loftier mountains, not on the east, as a barrier to intercourse with Europe, but off in the remote west, on the broad Pacific, where they stand open to the moist easterly winds as well as those of the west, to gather rains and snows, and make rivers and alluvial plains for the continent; and the waters of all the great streams, lakes, and seas make their way eastward to the narrow ocean that divides the civilized world. Europe has her slopes, rivers, and great seas opening into the same ocean; and even central Asia has her most natural outlet westward to the Atlantic. Thus, under this simple law, the civilized world is brought within one great country, the centre of which is the Atlantic, uniting the land by a convenient ferriage, and the *sides* the slopes of the Rocky Mountains and Andes on the *west*, and the remote mountains of Mongolia, India, and Abyssinia on the *east*.†

This subject affords an answer to the inquiry, What is a continent as distinct from an island? It is a body of land so large as to have the typical basin-form,—that is, mountain-borders about a low inte-

* First announced American Jour. Sci. [2], xvii., vols. iii. iv., 1847, and xxii. 335, 1856.

† See Guyot's Earth and Man.

rior. The mountain-borders of the continents vary from 500 to 1000 miles. Hence a continent cannot be less than a thousand miles (twice five hundred) in width.

3. SYSTEM IN THE COURSES OF THE EARTH'S FEATURE-LINES.

33. The system in the courses of the earth's outlines is exhibited alike over the oceans and continents, and all parts of the earth are thus drawn together into even a closer relation than appears in the principle already explained.

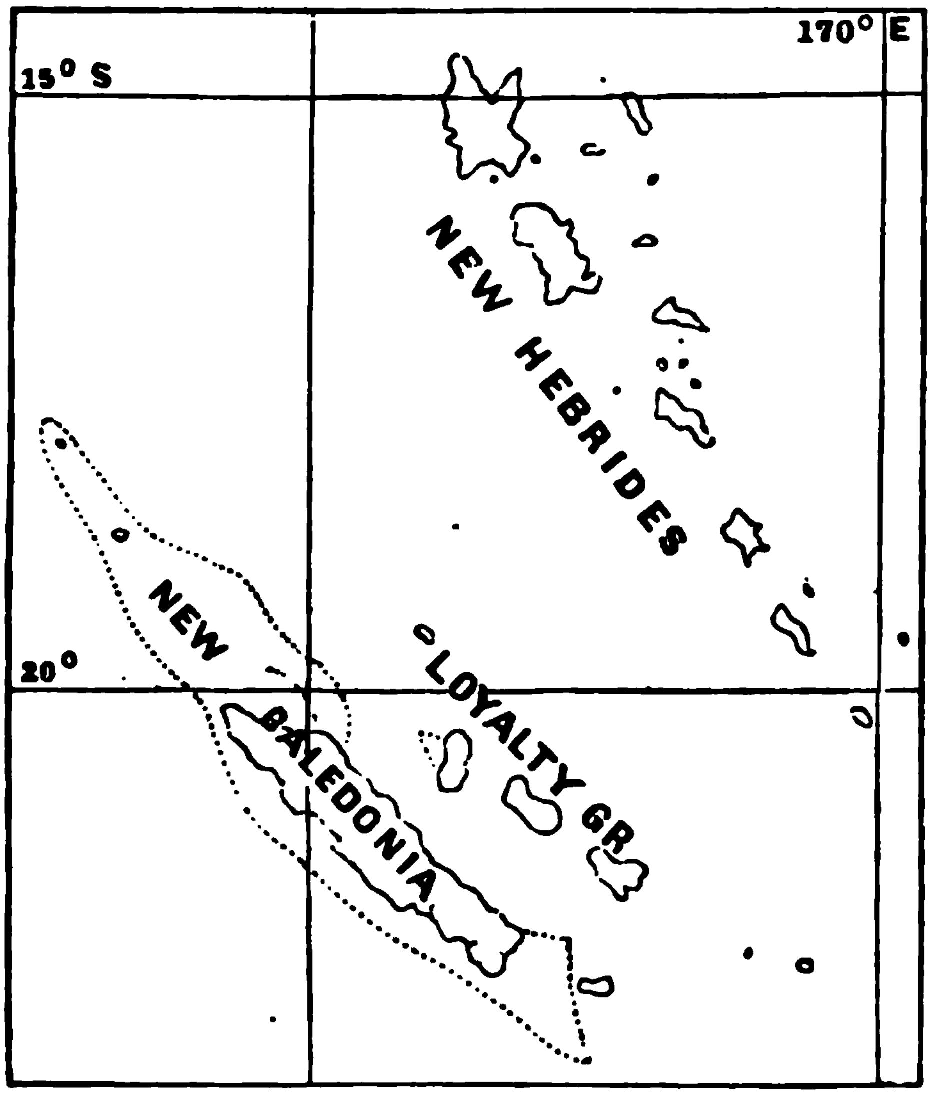
The principles established by the facts are as follow: That (1) two great systems of courses or trends prevail over the world, a *northwestern* and a *northeastern, transverse to one another;* (2) that the islands of the oceans, the outlines and reliefs of the continents, and the oceanic basins themselves, alike exemplify these systems; (3) that the mean or average directions of the two systems of trends are northwest-by-west and northeast-by-north; (4) that there are wide variations from these courses, but according to principle, and that these variations are often along curving lines; (5) that, whatever the variations, when the lines of the two systems meet, they meet nearly at right angles or transversely to one another.

34. (1.) **Islands of the Pacific Ocean.**—The lines or ranges of islands over the ocean are as regular and as long as the mountain-ranges of the land. To judge correctly of the seeming irregularities, it is necessary to consider that in chains like the Rocky Mountains, or Andes, or Appalachians, the ridges vary their course many degrees as they continue on, sometimes sweeping around into some new direction, and then returning again more or less nearly to their former course, and that the peaks of a ridge are very far from being in an exact line even over a short course; again, that several approximately parallel courses make up a chain.

A. Northwesterly system of trends.—In the southwestern Pacific, the *New Hebrides* (fig. 23) show well this linear arrangement; and even each island is elongated in the same direction with the group. This direction is nearly northwest (N. 40° W.), and the length of the chain is 500 miles. *New Caledonia*, more to the southwest, has approximately the same course,—about northwest. Between New Hebrides and New Caledonia lies another parallel line, the *Loyalty Group*. The *Salomon Islands*, farther northwestward, are also a linear group. The chain is mostly a double one, consisting of two parallel ranges, and each island is linear, like the group, and with the same trend. The course is northwest-by-west, the length 600 miles.

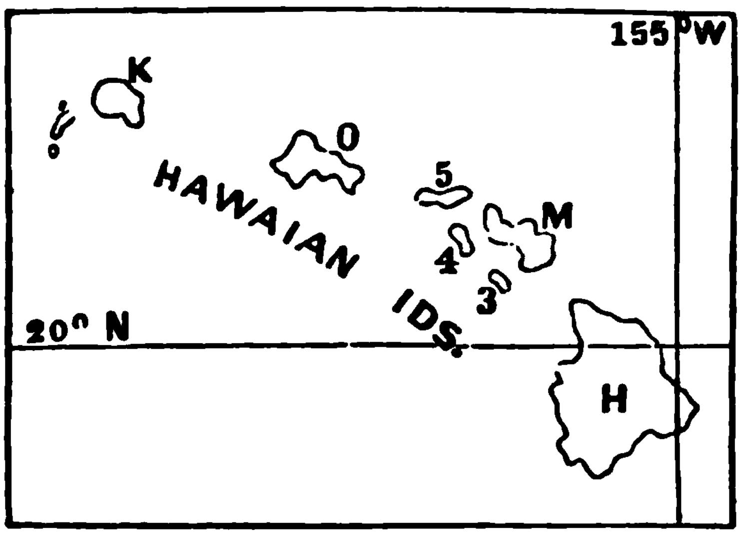
In the North Pacific, the Hawaian range has a west-northwest course. The Sandwich or Hawaian Islands (fig. 24), from Hawaii

Fig. 23.



to Kauai, make up the southeasterly part of the range, about 400 miles in length. Beyond this the line extends to 175° E., making

Fig. 24.



H, Hawaii; M, Maui; 3, Kahoolawe; 4, Lanai; 5, Molokai; O, Oahu; K, Kauai.

a total length of nearly 2000 miles,—a distance as great as from Boston to the Great Salt Lake in the Rocky Mountains, or from London to Alexandria. Moreover, in this chain there are on

Hawaii two summits nearly 14,000 feet in altitude; and if the ocean around is 15,000 feet deep, the whole height of these peaks is just that of Mount Everest in the Himalayas.

Between these groups lie the islands of the ocean, all nearly parallel in their courses. Figs. 25, 26 are examples.

Fig. 25.

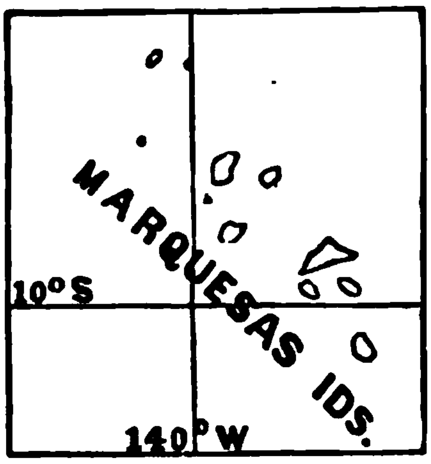
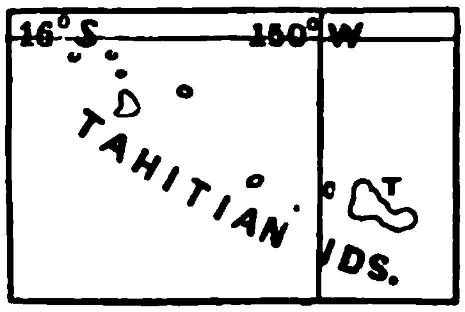


Fig. 26.



The following table gives the courses of the principal chains of the ocean:—

	Course.
Hawaian range	N. 64° W.
Marquesas Islands	N. 60° W.
Paumotu Archipelago	N. 60° W.
Tahitian or Society	N. 62° W.
Hervey Islands	N. 65° W.
Samoan or Navigator Islands	N. 68° W.
Tarawan or Kingsmill Islands	N. 34° W.
Ralick group	N. 37° W.
Radack group	N. 30° W.
New Hebrides	N. 40° W.
New Caledonia	N. 44° W.
North extremity of New Zealand	N. 50° W.
Salomon Islands	N. 57° W.
Louisiade group	N. 56° W.
New Ireland	N. 65° W.

B. Northeasterly system of trends.—The body of New Zealand has a northeast-by-north course. The line is continued to the south, through the Auckland and Macquarie Islands, to 58° S. To the north, in the same line, near 30° S., lie the Kermadec Islands, and farther north, near 20° S., the Tonga or Friendly Islands.

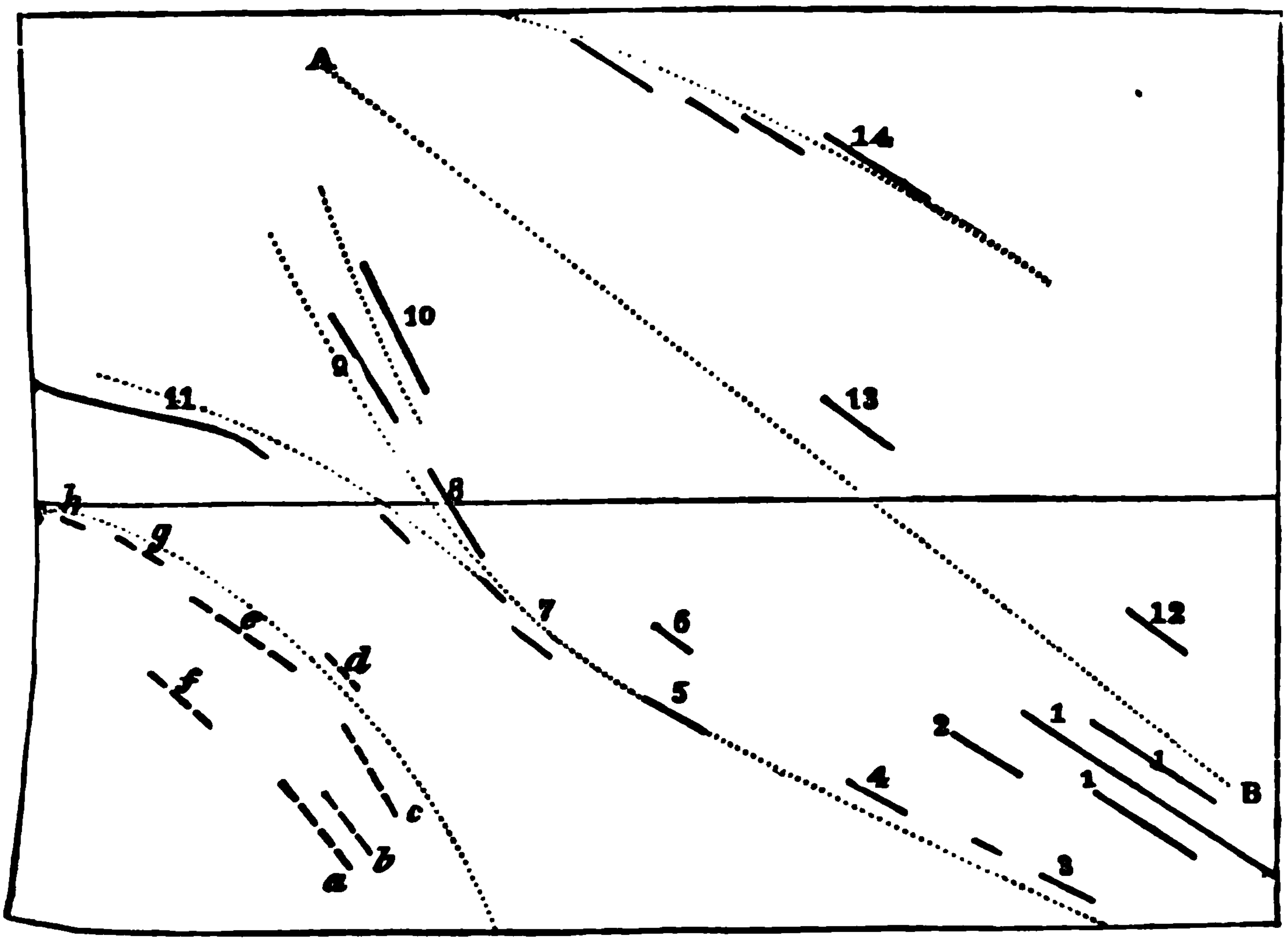
The Ladrones, north of the equator, follow the same general course. It also occurs in many groups of the northwesterly system characterizing subordinate parts of those groups. Thus, the westernmost of the Hawaian Islands, Nihau, lies in a north-northwest line, and the two lofty peaks of Hawaii have almost the same bearing.

35. Pacific island-chains.—The groups of Pacific islands, with a few exceptions, are not independent lines, but subordinate parts of island-chains. There are three great island-chains in the ocean which belong to the northwesterly system,—the *Hawaian*, the *Polynesian*, and the *Australasian*,—and, excluding the Ladrones, which belong to the western Pacific, one belonging to the northeasterly system, viz.: the *Tongan* or *New Zealand chain.*

(1.) *Hawaian chain.*—This chain has already been described.

(2.) *Polynesian chain.*—This chain sweeps through the centre of the ocean, and has a length of 5500 miles, or nearly one-fourth the circumference of the globe. The Paumotu Archipelago and the Tahitian and Hervey Islands are parallel lines in the chain, forming its eastern extremity; westward there are the Samoan and Tarawan groups and others intermediate; still northwestward there are the Radack and Ralick groups, and in 20° N., on the same line, Wakes Island.

Fig. 27.



1 to 10, the Polynesian chain: 1, Paumotu group; 2, Tahitian; 3, Rurutu group; 4, Hervey group; 5, Samoan or Navigators'; 6, Vakaafo group; 7, Vaitupu group; 8, Kingsmill group; 9, Ralick; 10, Radack; 11, Carolines; 12, Marquesas; 13, Fanning group; 14, Hawaian. a to h, part of the Australasian chain: a, New Caledonia; b, Loyalty group; c, New Hebrides; d, Santa Cruz group; e, Salomon Islands; f, Louisiade group; g, New Ireland; h, Admiralty group.

In fig. 27 the positions and trends of the various groups in this Polynesian chain are indicated by lines numbered from 1 to 10.

(*a.*) The chain, as is seen, consists of a series of parallel ranges succeeding and overlapping along the general course, in the manner illustrated on page 19, when speaking of mountains. (*b.*) It varies its course gradually from west-northwest at the eastern extremity to north-northwest at the western. (*c.*) Its mean trend is northwest-by-west (N. 56° W.), the mean trend of all the groups of the northwesterly system in the ocean. (*d.*) The chain is a curving chain, convex to the southward, and marks the position of a great central elliptical basin of the Pacific having the same northwesterly trend. The Hawaian is on the opposite side of it, slightly convex to the north.

The Marquesan range lies in the same line with the Fanning group to the northwest, just north of the equator; and, if a connection exists, another great chain is indicated,—a Marquesan chain.

(3.) *Australasian chain.*—New Hebrides and New Caledonia belong to the Australasian island-chain. The line of New Hebrides is continued northwestward in the Salomon group and New Ireland, though bending a little more to the westward, and terminates in Admiralty Land, near 145° E., where it becomes very nearly east-and-west: the length of the range is about 2000 miles. Taking another range in the chain, New Caledonia, the course is continued in the Louisiade group; then the north side of New Guinea, which continues bending gradually till it becomes east-and-west, near 135° E.: and in the southeast, belonging to the same general line, there is the foot of the New Zealand boot. The coral islands between New Caledonia and Australia appear also to be other lines in the chain.

From New Guinea the east-and-west course is taken up by Ceram, and again, more to the south, in the Java line of islands; and from Java the chain again begins to rise northward, becoming northwest finally in Sumatra and Malacca.

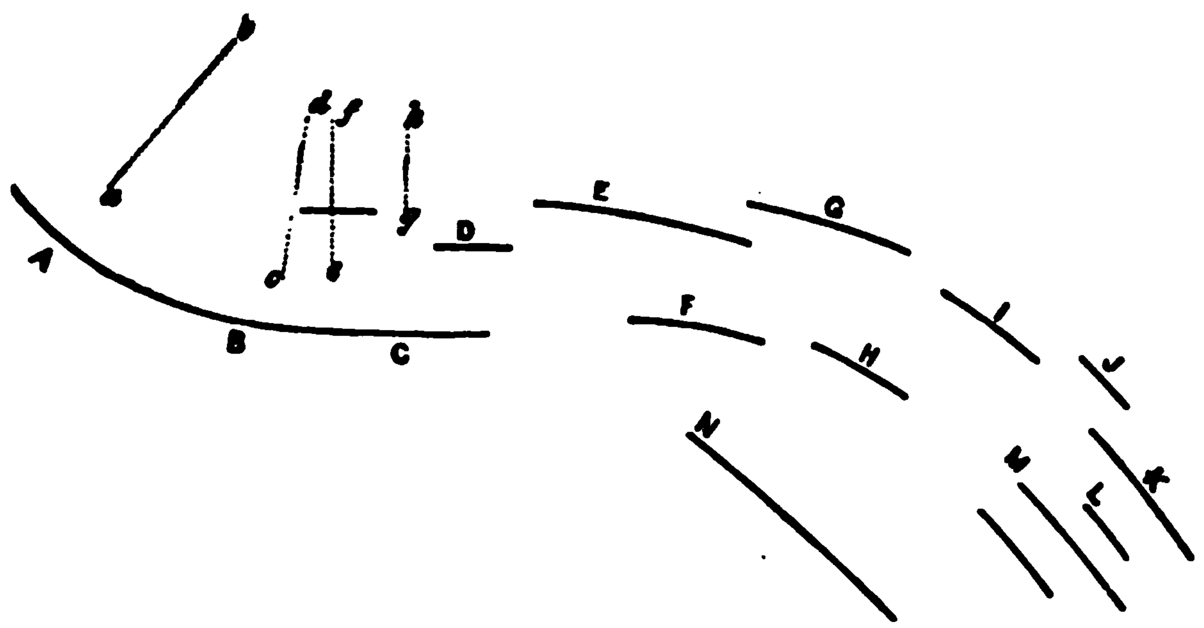
The several ranges make up one grand island-chain, with a double curvature, the whole nearly 6000 miles long. The relation of the parts in the system is shown in figure 28, in which a line stands for each group and indicates its course.

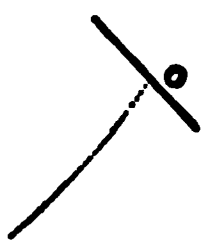
The composite nature of the chain is here apparent; as also the curving course, in connection with a prevailing conformity to a northwesterly trend.

(4.) *Blending of the Australasian and Polynesian island-chains.*—The two chains blend with one another in the region of the Carolines. This large archipelago properly includes the Ralick and Radack groups. At the Tarawan group, just south, the Polynesian chain divides into two parts,—the Ralick and Radack ranges. But the main body of the archipelago (see fig. 27 and the chart) trends off to

the westward, and is a third branch, conforming in direction to the Australasian system.

Fig. 28.





A, B, C, Sumatra and Java line of islands; D, Ceram; E, north coast of New Guinea; F, South New Guinea; G, Admiralty Islands; H, Louisiade group; I, Salomon; J, Santa Cruz group; K, New Hebrides; L, Loyalty group; M, New Caledonia; N, high lands of northeast Australia; O, New Zealand; *a b*, northwest shore of Borneo; *c d*, east Borneo; *e f*, west coast of Celebes; *g h*, west coast of Gilolo.

The Caroline Archipelago forks at its southeastern extremity,—one portion, the Tarawan, Radack, and Ralick Islands, conforming to the Polynesian system (8, 9, 10 in fig. 27), while the great body of the Caroline Islands trend off more to the westward (No. 11), parallel with New Zealand and the Admiralty group (*g*, *h* of the same cut) and others of the Australasian system.

(5.) *New Zealand chain.*—The ranges in this chain are mentioned in § 34. The whole length, from Macquarie Island, on the south, to Vavau, a volcanic island terminating the Tonga range, on the north, is 2500 miles. To the east of New Zealand lie Chatham Island, Beverly, Campbell, and Emerald, which correspond to another range in the chain.

This transverse chain is at right angles with the Polynesian system at the point where the two meet. Moreover, it is nearly central to the ocean; and in its course farther north lie the Samoan and Hawaian Islands, two of the largest groups in the Polynesian system.

The central position, great length, and rectangularity to the northwest ranges give great significance to this New Zealand or northeasterly system of the ocean.

The large Feejee group lies near the intersection of the three Pacific chains; and hence its numerous islands do not conform to either one, though the larger islands approximate most nearly to the last in direction.

36. (2.) **Pacific and Atlantic Oceans.**—The trend of the Pacific Ocean as a whole corresponds with that of its central chain of islands, and very nearly with the mean trend of the whole. It is a vast channel, elongated to the northeast. The range of heights along northeastern Australia runs from the eastern coast northwesterly, by the head of the great gulf (Carpentaria) on the north; and the opposite side of the ocean along North America, or its bordering mountain-chain, has a similar mean trend. A straight line drawn from northern Japan through the eastern Paumotus to a point a little south of Cape Horn may be called the axis of the ocean. This axial line is nearly half the circumference of the sphere, and the transverse diameter of the ocean full one-fourth the circumference: so that the facts relating to the Pacific chains must have a universal importance.

The *North Atlantic Ocean* trends to the northwest,—or at right angles, nearly, to the Pacific: this is the course of the coasts, and therefore of the channel. Taking the trend of the southeast coast of South America as the criterion, the *South Atlantic* conforms in direction to the North Atlantic.

The Asiatic coast of the Pacific has the direction of the northeasterly system. The course is not a nearly straight line, like the corresponding eastern coast of North America, but consists of a series of *curves*, which series is repeated in the outline of the Asiatic coast and in the mountains of the country back. Moreover, the curves *meet* one another at right angles.

The last one, which is 1800 miles long, commences in Formosa, and extends along by Luzon, Palawan, and western Borneo, to Sumatra, and terminates at *right angles* with Sumatra; and another furcation of it passes by eastern Borneo or Celebes, and terminates at *right angles* with Java and the islands just east (fig. 28). The rectangularity of the intersections is thus preserved; and the curve of the Australasian chain has in this way determined the triangular form of Borneo.

The Aleutian Islands (range No. 1) make a curve across from America to Kamtchatka, in length 1000 miles. The Kamtchatka range (No. 2) commences at right angles with the termination of the Aleutian, and bends around till it strikes Japan at a right angle. The Japan range (No. 3) commences north in Saghalien, and curves around to Corea. The Loochoo range (No. 4) leaves Japan at a right angle, and curves around to Formosa. The Formosa range (No. 5) is explained above. There is apparently a repetition of the Formosa system in the Ladrones near longitude 145° E.

37. (3.) **East and West Indies.**—The general courses in the East Indies have been mentioned in § 35. In the West Indies and Central America there is a repetition of the curves in the East Indies. The course of the range along Central America corresponds to Sumatra and Java; the line of Florida and the islands to the southeast makes another range in the same system.

The East and West Indies are very similar in their relations to the continents and oceans. About the *East* Indies Asia lies to the northeast and Australia to the southwest, just like North and South America about the *West* Indies; and the North Pacific and Indian Ocean have the same bearing about the former as the North Atlantic and South Pacific about the latter. The parallelism in the bends of the great chains is, hence, only a part in a wide system of geographical parallelisms.

38. (4.) **The American continents.**—In North America the *northwest* system is seen in the general course of the Rocky Mountains, the Cascade Range and Sierra Nevada; in Florida; in the line of lakes, from Lake Superior to the mouth of the Mackenzie; in the southwest coast of Hudson's Bay; in the shores of Davis' Straits and Baffin's Bay; and with no greater divergences from a common course than occur in the Pacific. The *northeast* system is exemplified in the Atlantic coast from Newfoundland to Florida, and, still farther to the northeast, along the coast of Greenland; and to the southwest along Yucatan, in Central America. The Appalachian Mountains, the river St. Lawrence to Lake Erie, and the northwest shore of Lake Superior, repeat this trend.

There are curves in the mountain-ranges of eastern North America like those of eastern Asia. The Green Mountains run nearly north-and-south, but the continuation of this line of heights across New Jersey into Pennsylvania curves around gradually to the westward. The Alleghanies, in their course from Pennsylvania to Alabama and Tennessee, have the same curve. There appears also to be an outer curving range, bordering the ocean, extending from Newfoundland along Nova Scotia, then becoming submerged, though indicated in the sea-bottom, and continued by southeastern New England and Long Island.

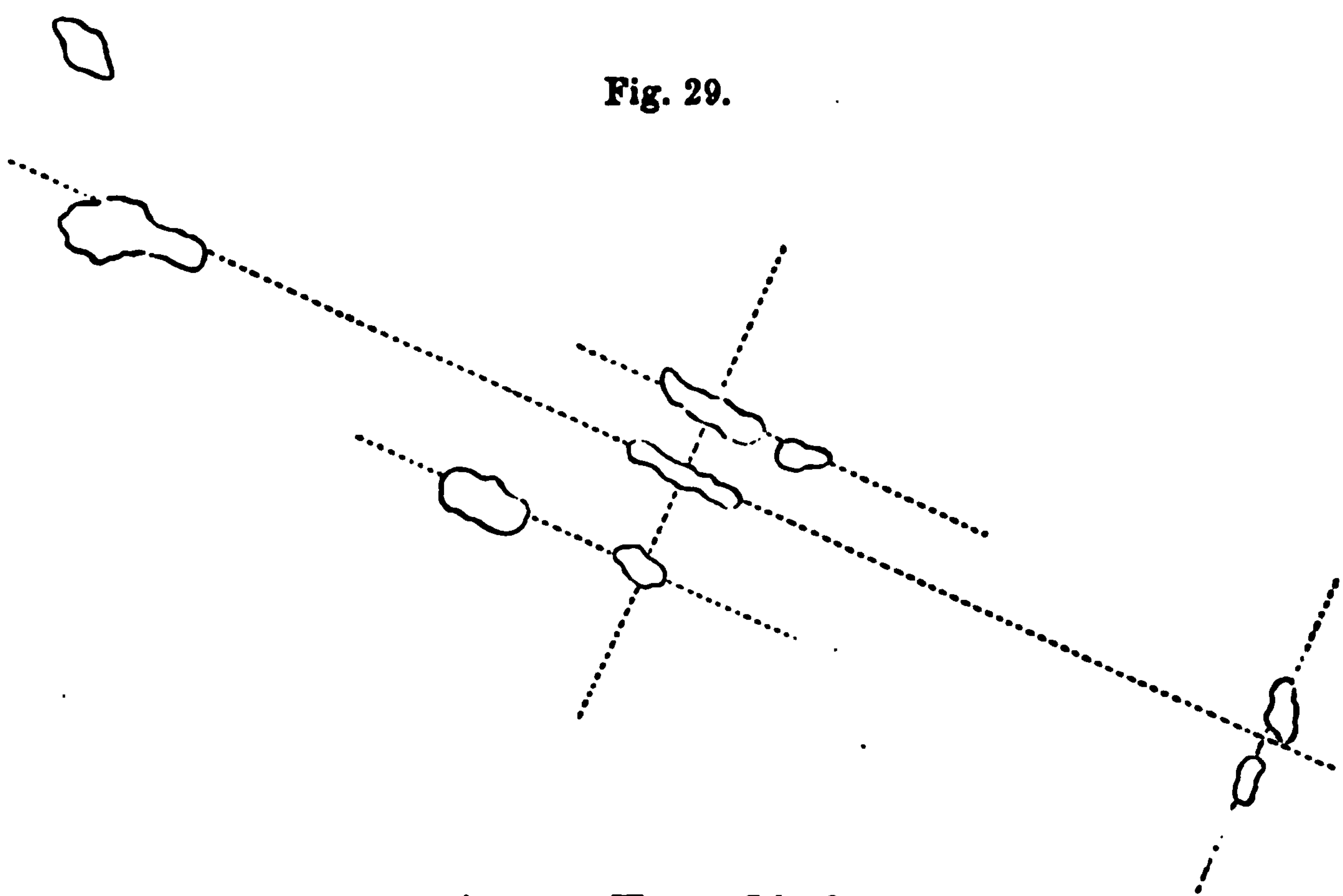
Between this range and that of the Green Mountains lies one of the great basins of ancient geological time, while to the westward of the Green Mountains and Alleghanies was the grand interior basin of the continent. The two were to a great extent distinct in their geological history, being apparently independent in their coal-deposits and in some other formations.

In South America the north coast has the same course as the

Hawaian chain, or pertains to the northwest system; and the coast south of the east cape belongs to the northeast system. Hence the outline of the continent makes a right angle at the cape. The northwest system is repeated in the west coast by southern Peru and Bolivia, and the northeast in the coast of northern Peru to Darien: so that this northern part of South America, if the Bolivian line were continued across, would have nearly the form of a parallelogram. South of Bolivia the Andes correspond to the northeast system, although more nearly north-and-south than usual.

39. (5.) **Islands of the Atlantic.**—The Azores have a west-northwest trend, like the Hawaian chain, and are partly in three lines,

Fig. 29.



Azores, or Western Islands.

with evidences also of the transverse system. The Canaries, as Von Buch has shown, present two courses at right angles with one another,—a northwest and a northeast.

Again, the line of the southeast coast of South America extends across the ocean, passes along the coast of Europe and the Baltic, and the mountains of Norway and the feature-lines of Great Britain are parallel to it.

6. **Asia and Europe.**—In Asia the Sumatra line, taken up by Malacca, turns northward, until it joins the knot of mountains formed by the meeting of the range facing the Pacific and that facing the Indian Ocean. At this point, and partly in continuation of a Chinese range, commence the majestic Himalayas,—at first east-and-west, at right angles with the termination of the Malacca

line, then gradually rising to west-northwest. The course is continued northwestward in the Hindoo Cush, extending towards the Caspian,—in the Caucasus, beyond the Caspian, and the Carpathians, beyond the Black Sea. The northwest course appears also in the Persian Gulf, and the plateaus adjoining, in the Red Sea, the Adriatic and Apennines.

40. **Recapitulation.**—From this survey of the continents and oceans it follows:—

That while there are many variations in the courses of the earth's feature-lines, there are two directions of prevalent trends,—the northwesterly and the northeasterly; that the Pacific and Atlantic have thereby their positions and forms, the islands of the oceans their systematic groupings, the continents their triangular and rectangular outlines, and the very physiognomy of the globe an accordance with some comprehensive law. The ocean's islands are no labyrinths, the surface of the sphere no hap-hazard scattering of valleys and plains; but even the continents have a common type of structure, and every point and lineament on their surface and over the waters is an ordered part in the grand structure.

It has been pointed out, first by Professor R. Owen, of Tennessee,* that the outlines of the continents lie in the direction of great circles of the sphere, which great circles are in general tangential to the arctic or antarctic circles. By placing the north pole of a globe at the elevation 23° 28′ (equal to the distance of the arctic circle from the pole or the tropical from the equator), then, on revolving the globe eastward or westward, part of these continental outlines, on coming down to the horizon of the globe, will be found to coincide with it; and on elevating the south pole in the same manner, there will be other coincidences. Other great lines, as part of those of the Pacific, are tangents to the tropical circles instead of the arctic. But there are other equally important lines which accord with neither of these two systems, and a diversity of exceptions when we compare the lines over the surfaces of the continents and oceans. Still, the coincidences as regards the continental outlines are so striking that they must be received as a fact, whether we are able or not to find an explanation, or bring them into harmony with other great lines.

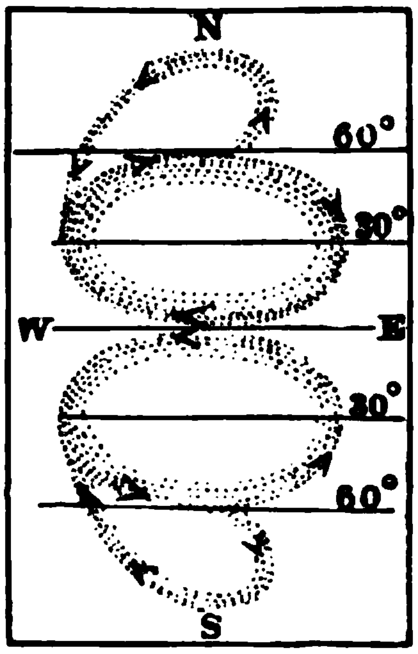
4. SYSTEM IN THE OCEANIC MOVEMENTS AND TEMPERATURE.

41. (1.) **System of oceanic movements.**—The general courses of the ocean's currents are much modified by the forms and positions of the oceans; but the plan or system for each ocean, north

* Key to the Geology of the Globe, 8vo, New York, 1857, and Am. Jour. Sci. [2], xxv. 130.

or south of the equator, is the same. This system is illustrated in the annexed figure (fig. 30), in which all minor movements are avoided in order to present only the predominant courses. W E is the equator in either ocean; 30°, 60°, the parallels so named; N, S, the opposite polar regions: the arrow-heads show the direction of the movement.

Fig. 30.



The main facts are as follow:—

(1.) A flow in either tropic (see figure) *from the east*, and in the higher temperate latitudes *from the west*, the one flow turning into the other, making an elliptical movement. The tropical waters may pass into the extratropical regions in all longitudes, but the movement is appreciable only towards the sides of the oceans.

(2.) A flow of a part of the easterly-flowing extratropical waters (see fig. 30) outward towards the polar region, to return thence with the polar waters mainly along the western side of the ocean (though partly by the eastern).

(3.) A flow of the colder current under the warmer when the two meet, since cold water, down to 39¼° F., is heavier than warm.

(4.) A lifting of the deep-seated cold currents to the surface along the sides of a continent or island, or over a submerged bank, as on the west coast of South America.

(5.) A movement of the circuit, as a whole, some degrees to the north or south with the change of the seasons, or as the sun passes to the north or south of the equator.

(6.) On the west side of an ocean (see fig. 30) the cold northerly current is mainly from the polar latitudes; on the east side it is mainly from the high temperate latitudes, being the cooled extratropical flow on its return.

(7.) The tropical current has great depth, being a profound movement of the ocean, and it is bent northward in its onward course by the deep, submerged sides of the continents. The Gulf Stream has consequently its main limit 80 to 100 miles from the American coast, where the ocean commences its abrupt depths (§ 17). Hence, a submergence of a portion of a continent sufficient to give the body of the current a free discharge over it would have to be of great depth,—probably two thousand feet at least.

42. The usual explanation of the courses is as follows:—As the

earth rotates to the eastward, the westward tropical flow is due simply to a slight lagging of the waters in those latitudes. But transfer these waters towards the pole, where the earth's surface moves less rapidly (the rate of motion varies as the cosine of latitude), and then they may move faster than the earth's surface and so have a movement to *eastward*. Thus, the tropical current *from the east* becomes an eastward one, or *from the west*, by mere change of latitude; and at some point intermediate there would be a region of no east-and-west movement. Any cause producing motion from the equator towards the poles, and the reverse, would therefore bring about the tropical and extratropical movements. On the same principle, any waters flowing from the polar regions (where the earth's motion at surface is slow) towards the equator would be thrown mainly against the *west side* of the oceans (as the Labrador current in the North Atlantic), for they have no power to keep up with the earth's motion. But the waters flowing towards the pole, that have not lost much of their previous eastward-moving force, may descend to lower latitudes along the east side of the ocean.

43. Put the above figure in either the Atlantic or Pacific, and the system for the ocean will be apparent at a glance.

In the North Atlantic the deep tropical current *from the east* is turned to the northward along the West India islands, and it there becomes the Gulf Stream; it flows by Florida to the northeast, following nearly the outline of the oceanic basin (§ 17); it passes the Newfoundland bank, and stretches over towards Europe; then a part bends southeastward to join the tropical current and complete the ellipse; the centre of this ellipse is the Sargasso Sea, abounding in seaweeds and calms. Another large portion continues on northeastward over the region between Britain and Iceland to the poles. From the polar region it returns along by Eastern Greenland, Davis' Straits, and other passages, pressing against the North American coast, throwing cold water into the Gulf of St. Lawrence, bringing icebergs to the Newfoundland banks, and continuing on southward to the West India islands and South American coast, where it produces slight effects in the temperature of the coast-waters. Cape Cod stands out so far that the influence of the cold current is less strongly felt on the shores south than north; and Cape Hatteras cuts off still another portion.

In the South Atlantic there is the tropical flow from the east; the bending south towards Rio Janeiro; the turn across towards Cape of Good Hope; and the bending again northward of the waters now cold. But, owing to the manner in which the channels

of the South Atlantic and North Atlantic are united, a large part of the tropical current of the former goes to swell the tropical current and Gulf Stream of the latter.

In the North Pacific there is the same system, modified mainly by this, that the connection with the polar regions is only through the narrow and shallow Behring Straits. There is a current answering to the "Gulf Stream" off Japan, and another corresponding to the "Labrador current" along the whole length of the Asiatic coast, perceptible by the temperature if not by the movement.

In the South Pacific there are traces of a "Gulf Stream"—that is, of an outward-bound tropical current—off Australia, noticed by Captain Wilkes. The inward extratropical current, chilled by its southern course, is a very important one to western South America, as it carries cool waters quite to the equator.

In the Indian Ocean the system exists, but with a modification depending on the fact that the ocean has no extended northern area. The outward tropical current is perceived off southeastern Africa.

The surface-currents of the ocean are more or less modified by changes in the winds. On this and on other related topics barely glanced at in this brief review the reader may refer to treatises on Meteorology or Physical Geography.

44. (2.) **Oceanic temperature.**—The movement of the oceanic currents tends to distribute tropical heat towards the poles, and polar cold, in a less degree, towards the tropics; and hence the courses of the currents modify widely the distribution of oceanic heat. The chart at the close of this volume contains a series of oceanic isothermal lines drawn through places of equal cold for the coldest month of the year. The line of 68° F., for example, passes through points in which the mean temperature of the water in the coldest month of the year is 68° F.; so with the line of 62°, 56°, &c.* All of the chart between the lines of 68°, north and south of the equator, is called the *Torrid Zone* of the ocean's waters; the region between 68° and 35°, the *Temperate Zone*, and that beyond 35°, the *Frigid Zone*. The line of 68° is that limiting the coral-reef seas of the globe, so that the coral-reef seas and Torrid Zone thus have the same limits.

The regions between the successive lines, as 80° and 80°, 80° and 74°, 74° and 68°, 68° and 62°, 62° and 56°, 56° and 50°, and so on, have special names on the chart. They are as follow :—

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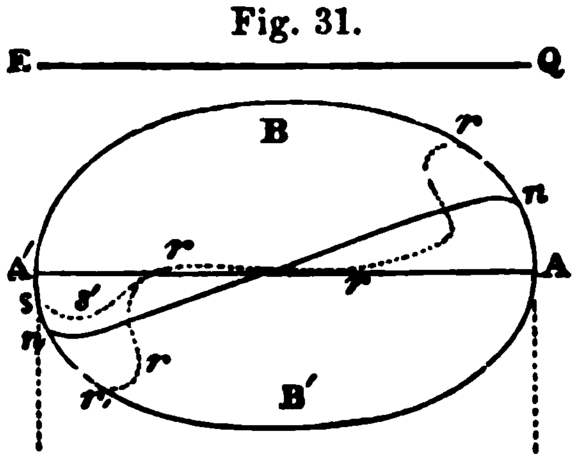
* As the lines are lines of equal extreme cold, instead of heat, such a chart is named an *isocrymal* chart (from ἴσος, *equal*, and κρυμος, *extreme cold*).

1. TORRID ZONE.—Super-torrid, torrid, and sub-torrid regions.
2. TEMPERATE ZONE.—Warm-temperate, temperate, sub-temperate, cold-temperate, and sub-frigid regions.
3. FRIGID ZONE.
They are convenient with reference to the geographical distribution of oceanic animals.

Since the tropical (the westward) currents are warm, and the extratropical (the eastward) necessarily cold, the elliptical interplay explained must carry the *warm* waters away from the equator on the *west* side of the oceans, and the *cold* waters towards the equator on the *east* side. The distribution of temperature thus indicates the currents. In each elliptical circuit, therefore, the line of 68° F. should be an oblique diagonal line to the ellipse; and thus it is in the North Atlantic, the South Atlantic, the North Pacific, the South Pacific (though less distinctly here, as the ocean is so broad), and the Indian Ocean. The torrid-temperature zones are very narrow to the eastward and broad to the westward. The temperate zones press towards the equator against western Africa and Europe, and western America. On the South American coast this is so marked that a tropical temperature does not touch the whole coast, except near the equator, and does not even reach the Galapagos under the equator off the coast, as shown by the course of the isothermal line of 68°. So in the South Atlantic the colder waters extend north to within six degrees of the equator, where the line of 68° leaves the African coast. The continuation of the Gulf Stream up between Norway and Iceland is shown by the great loops in the lines of 44° and 35°. The effect of the Labrador or polar current in cooling the waters on the coast of America is also well exhibited in the bending southward near the coast of all the lines from 68° to 35°. The polar current is even more strongly marked in the same way on the Asiatic coast. The lines from 74° to 35° have long flexures southward adjoining the coast, and the line of 68° comes down to within 15 degrees of the equator. These waters pass southward mostly as a submarine current, and are felt in the East Indies, making a southward bend in the heat-equator.

Fig. 31.



In figure 31 the elliptical line (A'B' A B) represents the course of the current in an ocean south of the equator (E Q). If now the movement in the circuit were equable, an isothermal line, as that of 68°, would extend obliquely across,

as *n n*: it would be thrown south on the west side of the ocean by the warmth of the torrid zone, and north on the east side by the cooling influence derived from its flow in the cold-temperate zone. But if the current, instead of being equable throughout the area, were mainly apparent near the continents (as is actually the fact), then the isothermal line should take a long bend near the coasts, as in the line A' *r' r r r r* A, or a shorter bend A' *s s'*, according to the nature of the current. This form of the isothermal line of 68° on the chart, hence, indicates the existence of the circuit movement in the ocean, and also some of its characteristics.*

45. The following are some of the uses of this subject to the geologist:—

1. A wide difference is noted between the water-temperatures of the opposite sides of an ocean. The regions named *temperate* and *sub-temperate* occupy the most of the Mediterranean Sea, and the Spanish and part of the African coast, on the European side, and yet have no existence on the American, owing to the meeting at Cape Hatteras of the cold northern waters with the warm southern. Compare also other oceans and coasts on the map.

2. Consequently, the marine productions of coasts or seas in the same latitudes differ widely. Corals grow at the Bermudas in 34° N., where the warmth of the Gulf Stream reaches, and, at the same time, are excluded from the Galapagos under the equator. Other examples of the same principle are obvious on the chart.

3. The *west* side of an ocean (as in the northern hemisphere) feels most the cold northerly currents when the continent extends into the polar latitudes; but the *east* side (as in the southern hemisphere), if the continent stops short of those latitudes. There is hence in the present age a striking difference between the northern and southern hemispheres.

4. Changes of level in the lands of the globe have caused changes of climates in the ancient world.

5. Knowing the temperature limiting the coral-reefs of the present era, or any species of plants or animals, the geologist has a gauge for comparing the present distribution of temperature and life with the past.

5. ATMOSPHERIC CURRENTS AND TEMPERATURE.

46. **General System.**—The system of atmospheric movement has a general parallelism with that of the ocean. In the tropics the flow is *from the east*, constituting what are called the *trades;* in high-temperate latitudes it is *from the west*; and the two pass into one

* See paper by the author, in Amer. Jour. Sci. [2] xxvi. 231.

another in mutual interplay. Between these is, in mid-ocean, a region of calms. The extratropical winds also in part pass on to the poles, to return, as northeast, north, and northwest winds, towards the equator.

The cause of the motion is not now considered, as it is here in place only to present in a comprehensive manner the earth's exterior features. The causes varying the directions consist in—(1) the temperature of the land and ocean; (2) the form of the land (mountains being barriers to a flow, retarding by friction, etc.); (3) difference of density of cold and warm air; (4) changing seasons, etc. But these sources of disturbance only modify without suspending the system of movement.

47. **Climate.**—Climate is determined by the atmospheric and oceanic movements and the distribution of land and water. The existing system may be briefly explained, in order to complete this survey of the earth's physiography.

1. The land takes up heat rapidly in summer, and, in the north, becomes frozen and snow-clad in winter. Land-winds may, consequently, be intensely hot or intensely cold; and hence lands have a tendency to produce extremes of climate.

A place on the continents having a mean January temperature of 50° (a very warm temperature for that season) is to be found only in warm latitudes, and one with a mean July temperature of 50° (a cold temperature for the season) only in the colder zones of the globe. The mean January temperature of New York is 31½° F., while the mean July temperature is 73°. Now, in North America the January isothermal line of 50° almost touches the Gulf of Mexico, and the July line of 50° passes near the mouth of Mackenzie River, or the arctic circle,—the extreme winters and intense summers causing this great change. In Asia, again, the January line of 50° runs just north of Canton, near 26° N., and the July line of 50° touches the Arctic Ocean at the mouth of the Lena, in 72° N., making a difference of 46° of latitude, or nearly 3000 miles, as the effect of the land on the climate.

2. The waters of the oceans remain unfrozen even far into the Arctic, unless crowded with lands, their perpetual movements tending to produce a uniformity of temperature over the globe; and hence winds from the oceans or any large body of water are moderating, and never very cold. They produce what is called an *insular* climate.

Great Britain is tempered in its climate by its winds and the oceanic current (the Gulf Stream). Fuegia, which is almost surrounded by water, also has an insular climate,—the winter's cold falling little below 32°, although below 56° S. latitude.

3. Absence of land from high latitudes is equivalent to an absence of the source of extreme cold; and from tropical lati-

tudes, that of extreme heat; and the sinking of all lands would diminish greatly both extremes. But sinking high-latitude lands also diminishes the extreme of heat, since the lands become very much heated in summer, and this heat is diffused by the winds. Fuegia, on this principle, has a subalpine climate with alpine vegetation; and Britain might approximate to the same condition if the Gulf Stream could be diverted into another ocean.

The mean temperature of the Northern hemisphere is stated by Dove at 60° F., and of the Southern at 56° F., while the extremes for the globe, taking the annual means, are 80° F. and *zero*. If there were no land, the mean temperature would probably be but little above what it is now, or not far from 60° for the whole globe.

6. DISTRIBUTION OF FOREST-REGIONS, PRAIRIES, AND DESERTS.

48. The laws of the winds are the basis of the distribution of sterility and fertility.

1. The warm tropical winds, or trades, are moist winds; and, blowing against cooler land, or meeting cooler currents of air, they drop the moisture in rain or snow. Consequently, the side of the continents or of an island struck by them—that is, the eastern—is the moister side.

2. The cool extratropical winds from the westward and high latitudes are only moderately moist (for the capacity for moisture depends on the temperature); blowing against a coast, and bending towards the equator, they become warmer, and continue to take up more moisture as they heat up; and hence they are *drying* winds. Consequently, the side of a continent struck by these westerly currents—that is, the *western*—is the drier side.

There is, therefore, double reason for the difference in moisture between the opposite sides of a continent.

Consequently, the annual amount of rain falling in tropical South America is 116 inches, while on the opposite side of the Atlantic it is 76 inches. In the temperate zone of the United States east of the Mississippi, the average fall is about 44 inches; in Europe, only 32. America is hence, as styled by Professor Guyot, the Forest Continent; and where the moisture is not quite sufficient for forests, she has her great prairies or pampas.

The particular latitudes of western coasts most affected by the drying westerly winds—those between 28° and 32°—are generally excessively arid, and sometimes true deserts. (W. C. Redfield, in Amer. Jour. Sci. xxv. 139, 1834, and xxxiii. 261, 1838.)

The desert of Atacama, between Chili and Peru, the semi-desert of California, the desert of Sahara, and the arid plains of Australia lie in these latitudes. The aridity on the North American coast is felt even beyond Oregon through half the year. The snowy peak of Mount St. Helen's, 16,000 feet high, in latitude 43°, stands for weeks together without a cloud. The region of the Sacramento has rain ordinarily only during three or four months of the year.

As the first high lands struck by moist winds usually take away the moisture, these winds afterwards have little or none for the lands beyond. Here is the second great source of desert-regions. For this reason, the region of the eastern Rocky Mountain slope, and the summits of these mountains, are dry and barren; and, on the same principle, an island like Hawaii has its wet side and its excessively dry side.

Under the influence of the two causes, Sahara is continued in an arid country across from Africa, over Arabia and Persia, to Mongolia or the Desert of Gobi, in central Asia.

It is well for America that her great mountains stand in the far west, instead of on her eastern borders to intercept the atmospheric moisture and pour it immediately back into the ocean. The waters of the great Gulf of Mexico (which has almost the area of the United States east of the Mississippi), and those of the Mediterranean, are a provision against drought for the continents adjoining. It is bad for Africa that her loftiest mountains are on her eastern border.

It is thus seen that prairies, forest-regions, and deserts are located by the winds and temperature in connection with the general configuration of the land.

49. The movements of the atmosphere and ocean's waters, and the surface-arrangements of heat and cold, drought and moisture, sand-plains and verdure, have a comprehensive disposing cause in the simple *rotation of the earth*. Besides giving an east and west to the globe, and zones from the poles to the equator, this rotation has made an east and west to the atmospheric and oceanic movements, and thence to the continents, causing the eastern borders of the oceans and land to differ in various ways from the western, and producing corresponding peculiarities over their broad surface. The continents, though in nearly the same latitudes on the same sphere, have thence derived many of those diversities of climate and surface which, through all epochs to the present, have impressed on each an individual character,—an individuality apparent even in its plants and animals. The study of the existing Fauna and Flora of the earth brings out this distinctive character of each

with great force; but the review of geological history makes it still more evident, by exhibiting the truth in a continued succession of faunas and floras, giving this individuality a history looking back to "the beginning."

The great truth is taught by the air and waters, as well as by the lands, that the diversity about us, which seems endless and without order, is an exhibition of perfect system under law. If the earth has its barren ice-fields about the poles, and its deserts, no less barren, towards the equator, they are not accidents in the making, but results involved in the scheme from its very foundation.

PART II.

LITHOLOGICAL GEOLOGY.

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50. LITHOLOGICAL GEOLOGY treats of the materials in the earth's structure: *first*, their *constitution*; *secondly*, their *arrangement* or *condition*. The earth's interior is open to direct investigation to a depth of only fifteen or sixteen miles; and hence the science is confined to a thin crust of the sphere, sixteen miles being but one-five-hundredth of the earth's diameter.

I. CONSTITUTION OF ROCKS.

51. **Rocks.**—A rock is any bed, layer, or mass of the material of the earth's crust. The term, in common language, is restricted to the consolidated material. But in Geology it is often applied to all kinds, whether solid or uncompacted earth, so as to include, besides granite, limestone, conglomerates, sandstone, clay-slates, and the like solid rocks, gravel-beds, clay-beds, alluvium, and any loose deposits, whenever arranged in regular layers or strata as a result of natural causes.

The constituents of rocks are minerals. But these mineral constituents may be either of *mineral* or *organic* origin.

(1.) The material of *organic origin* is that derived from the remains of plants or animals. This is the fact with the mass of nearly all the great limestone formations; for the substance of the rock was made from shells, corals, or crinoids, triturated into a calcareous earth by the sea, and afterwards consolidated, just as corals are now ground up and worked into great coral reef-rocks in the West Indies and Pacific. In other cases only a small part of a rock is organic, the rest being of mineral origin. Such rocks usually contain distinct remains of the shells or corals that have contributed to their formation: these relics, whether of plants or animals, are called *fossils*, and the rocks are said to be *fossiliferous*.

(2.) The material of *mineral origin* includes all that is not directly

of organic origin,—all the sand, clay, gravel, etc., derived from the trituration or wear of other rocks, or the material from chemical deposition, like some limestones, or from volcanic action, like lavas and trap or basalt.

But, whether organic or mineral in origin, the material when in the rock, though sometimes under the form of fossils, is almost solely in the *mineral* condition. The topics for consideration in connection with this subject are, then, as follow :—

1. The elements constituting rocks.
2. The mineral material constituting rocks.
3. The kinds of rocks.

1. ELEMENTS CONSTITUTING ROCKS.

52. **General considerations.**—In the foundation-structure of the globe firmness and durability are necessarily prime qualities, while in living structures instability and unceasing change are as marked characteristics.

These *diverse* qualities of the organic and inorganic world proceed partly from the intrinsic qualities of the elements concerned in each.

In the inorganic kingdom,—

(1.) The elements which combine with oxygen to become the essential ingredients of rocks are mainly hard and refractory substances: as, for example, *silicon*, the basis of quartz; *aluminium*, the basis of clay; *magnesium*, the basis of magnesia.

(2.) Or, if unstable or combustible elements, they are put into stable conditions by combination with oxygen. Thus, carbon, which we handle and burn in charcoal, becomes *burnt* carbon (that is, carbon combined with oxygen, forming carbonic acid) before it enters into the constitution of rocks. So all minerals are made of *burnt* compounds,—called *burnt* because ordinary combustion consists in union with oxygen and the production of stable oxyds. They are therefore dead or inert in ordinary circumstances, and hence fit for *dead* nature. The metals *potassium* and *sodium* burn if put in contact with water, and become oxyds. They are made into these stable oxyds, potash and soda, before entering as ingredients into rocks. *Calcium* also becomes lime,—one of the most refractory of substances; and *magnesium* magnesia,—even more refractory than lime. *Silicon* unites with its full allowance of oxygen in order to form quartz, the most abundant compound in the mineral kingdom and the least liable to change. *Aluminium* combines with a saturating quantity of oxygen to form alumina, the constituent of sapphire and emery, the characterizing ingredient of clay, and hardly less universal than quartz.

In organic nature, on the contrary,—

(1.) The essential elements are combustible substances, and mostly gases,—oxygen combined with carbon and hydrogen forming plants, and oxygen with carbon, hydrogen, and nitrogen forming animal substances.

(2.) The elements in living beings, moreover, are not saturated with oxygen: they are therefore in an unstable and constrained condition. Both from their nature and their peculiar condition, they have a strong tendency to take oxygen from the atmosphere with which they are bathed or penetrated, and combine with it. This state of strong attraction for oxygen—for something not in the structure itself—is the source of activity in the vital functions, and involves unceasing change as the means of existence and growth, and a final dissolution of the structure at the cessation of life.

Hence strength and durability belong to the basement-material of the globe, and instability to living structures.

But inorganic nature is still not without change. For there are diversities of attraction among the elements and their compounds. The changes are, however, slow, and not essential to the existence of the compounds. The processes of solution, of oxydation and deoxydation, and other chemical interactions, changes by heat, and other molecular and mechanical influences, give a degree of activity even to the world of rocks. But this topic belongs to the dynamics and chemistry of geology.

53. **Characteristic elements.**—The elements most important in rocks are the following:—

(1.) *Oxygen.*—Oxygen is a constituent of all rocks, and composes about one-half by weight of the earth's crust.

Sand is, by weight, more than half oxygen; quartz, the principal material of sand, is about 53 per cent. oxygen; common limestone, 48 per cent.; alumina, nearly 47 per cent.; feldspar, 46 to 50 per cent.; common clay, 50 per cent.: and thus it is with the various ordinary rocks. Besides, the atmosphere contains 23 per cent. of oxygen, and water—the material of the oceans, lakes, and rivers—89 per cent.

(2.) *Silicon.*—After oxygen, silicon is the element next in abundance, constituting at least a fourth of the earth's crust. It is unknown in nature in the pure state; but combined with oxygen, and thus forming silica or quartz, it is common everywhere. This silica is an acid, although tasteless; and its combinations with alumina, magnesia, lime, and other bases (called *silicates*), along with quartz, are the principal constituents of all rocks except the limestones. Silica constitutes about 60 per cent. of these ingredients;

and, including the limestones, 50 per cent. of all rocks. Silicon has therefore the same prominent place in the mineral kingdom as carbon in the organic.

Granite and gneiss are nearly three-fourths silica,—half of it as pure quartz, and the rest as silicates; mica schist and roofing-slate are about two-thirds silica; trap and lavas are one-half; porphyry, two-thirds; sandstones are sometimes all silica, and usually at least four-fifths.

Silica is especially adapted for this eminent place among the architectural materials of the globe by its great hardness, its insolubility and resistance to chemical and atmospheric agents, and its infusibility. As it withstands better than other common minerals the wear of the waves or streams, besides being very abundant, it is the prevailing constituent of sands, and of the movable material of the earth's surface, as well as of many stratified rocks; for the other ingredients are worn out by the quartz under the constant trituration. It is also fitted for its prominent place by its readiness in forming siliceous compounds and the durability of these silicates. Moreover, although infusible and insoluble, many oxyds enable heat to melt it down and form glass; or, if but a trace of alkali be contained in waters, those waters, if heated, have the power of dissolving it; and, thus dissolved, it may be spread widely, either to enter into new combinations, or to fill with quartz fissures and cavities among the rocks, thereby making veins and acting as a general cement and solidifier.

Its applications in world-making are, therefore, exceedingly various. In all, its action is to make stable and solid.

(3.) *Aluminium.*—Aluminium is a white metal, between tin and iron in many of its qualities, but as light as chalk. Combined with oxygen it forms alumina (Al^2O^3), the basis of clay. This alumina is the gem sapphire, which is next in hardness to the diamond, and of extreme infusibility and insolubility. Alumina is the most common base in the silicates, thereby contributing to a large part of all siliceous minerals, and therefore of all rocks. With quartz these compounds (aluminous silicates) make granite, gneiss, mica schist, syenite, and some sandstones, and alone they form porphyry and other igneous rocks. Nearly all the rocks, except limestones and some sandstones, are literally ore-beds of the metal aluminium.

(4.) *Magnesium.*—This metal combined with oxygen forms magnesia (MgO), a very refractory and insoluble base, producing with silica a series of durable silicates, very widely distributed: some are quite hard, as hornblende and pyroxene; others are soft, and have a greasy feel, like talc, soapstone, and serpentine.

Unlike alumina, magnesia unites with carbonic acid, forming *carbonate of magnesia* (MgO,CO^2).

(5.) *Calcium.*—The oxyd of the metal calcium is common quicklime. Like magnesia, it enters into various silicates; and it also forms a carbonate, *carbonate of lime* (CaO,CO^2), and this carbonate is the material of limestones. Moreover, with sulphuric acid and water it forms *sulphate of lime*, or gypsum.

The peculiar position of lime in the system of nature is that of a medium between the organic and inorganic world. Carbonate of lime is soluble in water which holds a little carbonic acid in solution; and both this and the sulphate are found in river, marine, and well waters. It is made into shells, corals, and partly into bone by animals, and then turned over to the inorganic world to make rocks. Lime is, therefore, the medium by which organic beings aid in the inorganic progress of the globe, as above stated: far the greater part of limestones have been made through the agency of life, either vegetable or animal.

Lime also unites with phosphoric acid, forming *phosphate of lime*, the essential material of bone, and a constituent also of other animal tissues. Like the carbonate, this phosphate is afterwards contributed to the rock-material of the globe, and is one source of mineral phosphates.

(6.) (7.) *Potassium* and *sodium.*—Potassium is the metallic base of *potash*, and sodium of *soda*. The alkalies potash and soda, besides some other oxyds, form glass or fusible compounds with silica; and this fact indicates one of their special functions in the earth's structure. Silica, alumina, and the pure silicates of alumina are quite infusible; but by the addition of the alkalies, or the oxyds of iron or lime, fusible compounds are formed. And, as the earth's early history was one of universal fusion, the alkalies performed an important part in the process, as they have since in all igneous operations. Feldspars, which are found in all igneous rocks, are silicates of alumina with potash, soda, or lime. A heated solution of potash or soda will also dissolve silica, and so aid in distributing quartz or making silicates.

Sodium is likewise the basis of common salt in sea-water.

(8.) *Iron.*—Iron combines with oxygen and forms two compounds, a protoxyd FeO, and a sesquioxyd Fe^2O^3, and one or the other occurs along with alumina, magnesia, or lime in many silicates, which are mostly fusible. Silica and magnesia or lime with protoxyd of iron make part of the very abundant mineral *hornblende*, found in syenite, hornblendic slate, etc.; and also the

equally common *pyroxene*, characteristic of the heavy, dark-colored lavas.

(9.) *Carbon.*—Carbon is well known in three different states,—that of the diamond, the hardest of known substances, that of graphite or black lead, and that of charcoal. Combined with oxygen it forms carbonic acid (CO^2); and carbonic acid combined with lime makes carbonate of lime, or common limestone; with magnesia, carbonate of magnesia, or magnesite; with protoxyd of iron, carbonate of iron, or spathic iron; etc.

Carbonic acid exists in the atmosphere, constituting ordinarily about one part in twenty-five hundred by weight.

This acid is the only acid in the mineral kingdom, in addition to silica, which enters very largely into the constitution of rocks; and, while silica has alumina and other sesquioxyds wholly to itself, carbonic acid shares with it in the magnesia, lime, and alkalies, that is, in all the protoxyds. Carbon, we have said, performs as fundamental a part in living nature as silicon in dead nature; and it is mainly through living beings that it reaches the mineral kingdom and forms limestones and coal-beds. The deposits of carbonate of lime that have been produced by direct chemical deposition from the waters of the globe are small compared with those made of organic remains of plants or animals.

The *nine* elements above mentioned, *oxygen, silicon, aluminium, magnesium, calcium, potassium, sodium, iron,* and *carbon,* are the prominent constituents of rocks, making up 977-1000ths of the whole.

(10.) *Sulphur.*—Sulphur exists native in volcanic and some other regions. In combination with various minerals it forms ores called *sulphurets*, as sulphuret of iron, or pyrites, sulphuret of copper, sulphuret of silver. But these sulphurets do not constitute properly beds of rock; although one of them, pyrites, is very abundant. Sulphur forms with oxygen two acids, *sulphurous* acid (SO^2), and *sulphuric* acid (SO^3). Sulphuric acid united with lime makes sulphate of lime, or gypsum, which sometimes occurs in extensive beds. There are also many other sulphates, but none as true rock-constituents.

(11.) *Hydrogen* with oxygen constitutes water; and water, besides being abundant over the earth's surface, is a constituent of many minerals. Gypsum contains 21 per cent., serpentine 13 per cent., talc 5 per cent.

(12.) *Chlorine* with sodium forms chlorid of sodium, or common salt, which is found in large beds, as well as dissolved in sea-water and brine-springs.

(13.) *Nitrogen* is an ingredient of the atmosphere,—making 77 per cent. of it. With oxygen it forms nitric acid (NO^5); but no nitrates enter prominently into the structure of rocks.

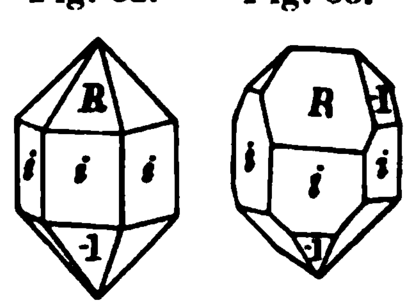
The thirteen elements mentioned are all that occur as important rock-constituents. Others require attention in discussing topics connected with chemical geology, in which department the profoundest knowledge of chemistry and mineralogy is none too much. But in a general review of rocks only these thirteen need be considered.

2. MINERALS CONSTITUTING ROCKS.*

1. *Quartz, and Silicates containing alumina, without water.*

54. (1.) QUARTZ.—Quartz is the first in importance. It occurs in crystals, like figs. 32 and 33; also massive, with a glassy lustre. Hardness too great to be scratched with a knife; varies in color from white or colorless to black, and in transparency from transparent quartz to opaque. It has *no cleavage*,—that is, it breaks as easily in one direction as another, like glass. Before the blowpipe it is infusible, unless heated with soda, when it fuses easily to a glass. Clear kinds are called *limpid* quartz; violet crystals are the *amethyst*; compact translucent, with the colors in bands or clouds, *agate*; or without bands or clouds, *chalcedony*; massive, of dark and dull color, with the edges translucent, *flint*; the same with a splintery fracture, *hornstone*; the same more opaque, *lydianstone* or *basanite*; the same of a dull red, yellow, or brown color, and opaque, *jasper*; in aggregated grains, *sandstone* or *quartzite*; in loose, incoherent grains, *ordinary sand.*

Fig. 32. Fig. 33.



Silica also occurs in another state, constituting *opal*, a well-known mineral. In this state it is easily dissolved in a heated solution of potash, while quartz is not so dissolved. Opal usually contains some water, and is a little softer than quartz.

55. (2.) FELDSPAR.—Feldspar is next in abundance to quartz. Under this name several species are included, all of which contain silica and alumina; but one has, in addition, potash, and is a *potash-feldspar*; another, *soda*,—a *soda-feldspar*; another, lime,—a *lime-feldspar*; and others, both soda and potash, or soda and lime. They are all similar in being nearly as hard as quartz; in having a lustre somewhat like quartz, though partly pearly on smooth faces; in general, only light colors, white and flesh-red being most common; also a broad, even, lustrous cleavage-surface, with a second cleavage nearly or quite at right angles with the other, and but little less perfect. Specific gravity, between 2.4 and 2.8. Before the blowpipe,

---

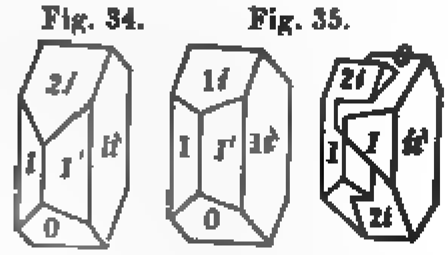
* The ordinary characters by which minerals are distinguished are—relative *hardness*, as ascertained by a file, a point of a knife, or by scratching one mineral with another; *specific gravity*, or relative weight; *lustre* and *color*; *crystalline form*; *cleavage* (cleavage being a facility of cleaving or breaking in some one or more directions, and affording even, lustrous surfaces, as in *mica, gypsum, feldspar*); *fusibility*; *chemical composition.*

melts with difficulty. The lustrous cleavage-surface serves to distinguish it from quartz when the two occur together, as in granite.

In the feldspars the ratio of the alumina to the protoxyd bases (potash, soda, or lime) is uniformly 1 . 1.

a. ORTHOCLASE, or *potash-feldspar*, is the most common, and is often called common feldspar. Crystals as in the annexed figures (monoclinic). The two cleavage-planes are *at right angles* with one another. Colors, usually white or flesh-red. *Composition:* Silica, 64.8, alumina, 18.4, potash, 16.8 = 100. Ratio of the potash, alumina, and silica, 1 : 1 · 4.

Fig. 34. Fig. 35.



b. ALBITE, or soda-feldspar, is also common. Color, generally white, whence the name (from the Latin *albus, white*). Crystals, triclinic; the two cleavage-planes incline to one another at the angle 93° 36'. Plane O of crystals often striated in only one direction. *Composition:* Silica, 68.7, alumina, 19.5, soda, 11.8. Ratio of the soda, alumina, and silica, 1 : 1 : 4. Some albites contain a little potash, and some orthoclases a little soda.

c. OLIGOCLASE, a lime-and-soda feldspar. Resembles albite in crystallization and appearance. Ratio of the protoxyds (lime and soda), alumina, and silica, 1 : 1 : 3. *Andesine* is another lime-and-soda feldspar. Ratio of the protoxyds, alumina, and silica, 1 : 1 · 2⅔. They are distinguished from albite with difficulty without chemical analysis.

d. LABRADORITE, or lime-feldspar Colorless to grayish and smoky brown, and usually with beautiful internal reflections. Crystallization nearly as in albite. *Composition:* Silica, 53.1, alumina, 30.1, lime, 12.3, soda, 4.5. Ratio of protoxyd bases, alumina, and silica, 1 : 1 : 2.

e. ANORTHITE is another lime-feldspar, but of less common occurrence, being mostly confined to certain volcanic rocks. *Composition:* Silica, 43.2, alumina, 36.8, lime, 20.0. Ratio of lime, alumina, and silica, 1 : 1 : 1⅓.

Anorthite and *labradorite* differ from the other feldspars in containing proportionally less of silica and being decomposable easily by acids.

56. (3.) MICA.—Readily distinguished by its splitting easily into very thin elastic leaves or scales,—even thinner than paper,—and its brilliant lustre. It is colorless to brown, green, reddish, and black. It may occur in small scales,—as common in granite as one of its constituents,—or in plates a yard in diameter.

As with the feldspars, mica is a silicate of alumina and different bases with usually some fluorine, and is of several kinds, which differ in composition and optical characters more than in appearance. Some of the varieties resemble talc and chlorite, from which they differ in being elastic (unless weathered).

a. MUSCOVITE, or common mica, is a *potash-mica*. Its crystals, when distinct, are oblique prisms, and by polarized light it affords two sets of rings, with the angle between the two axes 60° to 75°. *Composition:* Silica, 46, alumina,

36, sesquioxyd of iron and manganese, 5.0, potash, 10, fluorine, 1.0. A variety called *lepidolite* has often a violet color and contains lithia.

b. Phlogopite.—A *magnesia-mica.* Crystals right prisms, rhombic or hexagonal. Color, yellowish-brown to white, often a little like copper in its reflections. By polarized light, biaxial, with the angle between the axes 5° to 20°. Contains, besides silica, alumina, and magnesia, some potash and oxyd of iron. Found mostly in crystalline limestones.

c. Biotite.—A *magnesia-mica,* usually containing much oxyd of iron. Crystals right or oblique prisms. Color, often black, and greenish black; rarely white. By polarized light, nearly or quite uniaxial, the angle between the axes, when distinctly biaxial, but 1° or 2°. Contains, besides silica, alumina, and magnesia, much oxyd of iron and some potash.

Fig. 36.

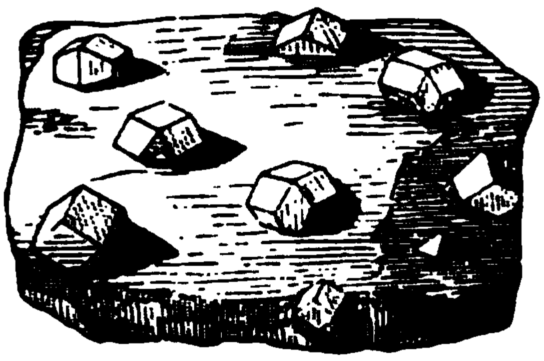
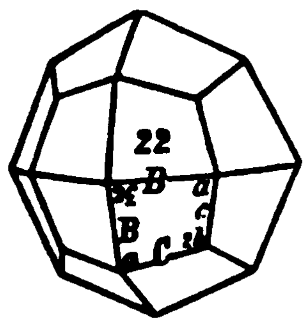


Fig. 37.



57. (4.) Garnet.—Crystals usually dodecahedrons (fig. 36, imbedded in the rock), trapezohedrons (fig. 37), and combinations of these forms, and commonly imbedded in gneiss, mica slate, and other crystalline rocks. Color, clear wine and cinnamon red to reddish-brown and black; rarely green. Hardness equal to that of quartz, and therefore not scratched by a knife. G. = 3.1–4.3, the heavier kinds containing much iron. Before the blowpipe, fuses rather easily. *Composition:* Silica and alumina, with either lime, magnesia, or oxyds of iron, and sometimes protoxyd of manganese or chromic oxyd. The lime variety (cinnamon-stone) contains silica, 40.1, alumina, 22.7, lime, 37.2. But some oxyd of iron is generally present; and common garnet contains silica, 36.3, alumina, 20.5, protoxyd of iron, 43.2. The ratio of protoxyds, peroxyds, and silica is 1:1:2.

Idocrase resembles garnet closely in color, composition, and fusibility, but is square-prismatic in its crystals, and brownish in color like some brown garnet and tourmaline.

(5.) Leucite.—In trapezohedral crystals like garnet, but white or gray and without cleavage. Hardness nearly that of feldspar. G. = 2.45–2.5. Occurs in Vesuvian lavas in crystals and grains. *Composition:* Silica, 55.1, alumina, 23.4, potash, 21.5.

58. (6.) Epidote.—Crystals oblique prisms (monoclinic). Also occurring massive, with a granular or columnar structure. Prevailing color, a peculiar yellowish green, but varying to brown, ash-gray, and white. Hardness = 6–7, or nearly that of quartz. G. = 3.2–3.5. *Composition:* Constituents, same essentially as in garnet, but ratio 3:2:3. There is a *lime* variety, containing silica, 42.5, alumina, 31.5, lime, 26.0; and a *lime*-and-*iron* variety, containing silica, 39.5, alumina, 19.5, peroxyd of iron, 17.0, lime, 24.0.

59. (7.) Scapolite.—Crystals square and eight-sided prisms, and often large and cleaving imperfectly parallel to the sides of the square prism. (See fig. 38.) Color, white, gray, or greenish gray, and looking much like feldspar, though

Fig. 38.

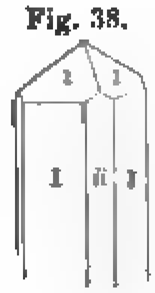
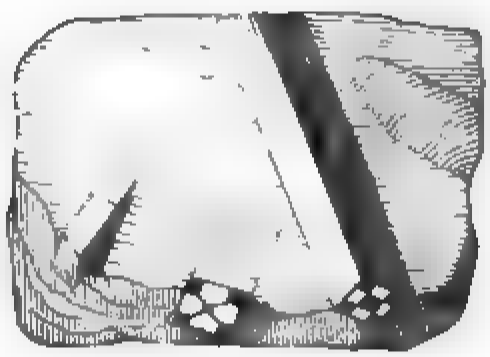


Fig. 39.

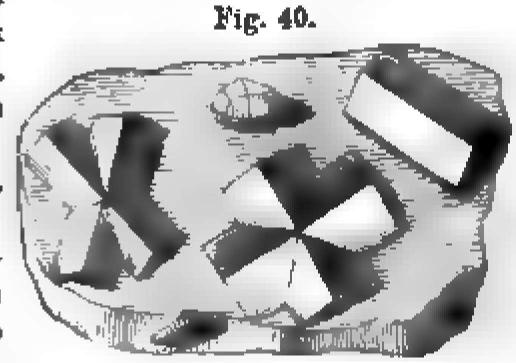


distinct in crystallization and cleavage. Hardness but little below that of feldspar. G. = 2.6–2.75. *Composition:* Silica, 49.3, alumina, 27.9, lime, 22.8, but usually containing some soda.

60. (8.) Andalusite.—Occurs in whitish or grayish prismatic crystals, nearly square (angle of 90° 44′), and often having the interior tessellated with black (fig. 39), in which case it is usually called *macle*, or *chiastolite*. Hardness, if pure, greater than that of quartz. G. = 3.1–3.2. Before the blowpipe, infusible. *Composition:* Silica, 37.0, alumina, 63.0.

61. (9.) Staurotide.—In rhombic prisms of a large angle (129° 20′), often having the acute edges removed so as to be six-sided. Often in crossed crystals (fig. 40), whence the name, from the Greek *σταυρός, a cross*. Crystals usually thick and coarse, sometimes fine lustrous. Color, brown to black. A little harder than quartz. G. = 3.5–3.75. Before the blowpipe, infusible. *Composition:* Silica, 29.3, alumina, 53.5, peroxyd of iron, 17.2.

Fig. 40.



62. (10.) Kyanite.—In flattened, blade-like, rarely thick prisms, blades often aggregated into masses. Color, sky-blue to white, usually deeper blue along the middle. Hardness of the extremities of the prisms as great as that of quartz. G. = 3.5–3.7. Before the blowpipe, infusible. Same *composition* as andalusite. *Sillimanite* is similar in *composition*, but has a brownish to grayish color, a brilliant cleavage in one direction, and it often runs into fibrous forms. G. = 3.2–3.3.

Fig. 41.

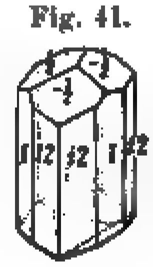
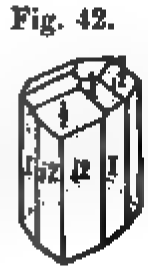


Fig. 42.

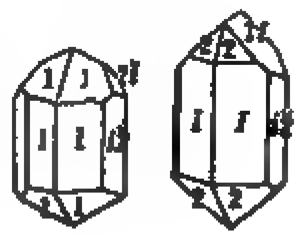


63. (11.) Tourmaline.—In three, six, nine, or twelve-sided prisms (figs. 41, 42), without vertical cleavage, and when black a little pitch-like in the cross-fracture. Color, commonly black; also brown; rarely green, and pink or carmine red. As hard as quartz. G. = 2.9–3.3. The crystals are thick or coarse, and often penetrate quartz (fig. 43) in long black prisms as large as a goose-quill; also found in mica

schist in long or short prisms, frequently as large as the finger, or larger, and in soapstone in black or brown crystals, long or short. Before the blowpipe

Fig. 43.

Fig. 44. Fig. 45.



the common varieties fuse easily. *Composition* peculiar in the presence of boracic acid; the other constituents, besides silica and alumina, are commonly some magnesia, oxyd of iron, soda, and fluorine.

64. (12.) TOPAZ.—In rhombic prisms (figs. 44, 45) of 124° 19′, having a brilliant and easy cleavage parallel to the base. Sometimes columnar-massive. Color, pale yellow, white, brown; often transparent. Harder than quartz. G. = 3.4–3.7. Before the blowpipe, infusible. *Composition* peculiar in the large amount of fluorine present; contains—Silica, 35.27, alumina, 54.92, fluorine, 17.14.

BERYL.—In regular six-sided prisms, without distinct cleavage. Color, usually pale green; in the emerald—a variety of beryl—deep and clear green; also yellowish, bluish, brownish, white. Hardness above that of quartz. G. = 2.65–2.75. Infusible. Composition peculiar in containing glucina. *Composition:* Silica, 66.9, alumina, 19.0, glucina, 14.1 = 100.

2. *Protoxyd-Silicates, not containing water.*

65. (13.) HORNBLENDE (often called AMPHIBOLE).—In oblique prismatic crystals (monoclinic) of 124° 30′, with cleavage parallel to the faces; often having the acute edges truncated so as to be six-sided and approach a regular hexagonal prism. The crystals often long and thin (fig. 48), or aggregated into masses, or penetrating the rock (fig. 49); sometimes short and stout (figs. 46 and 47). Color,

Fig. 46. Fig. 47.

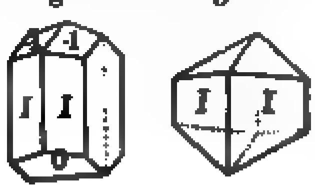


Fig. 48.

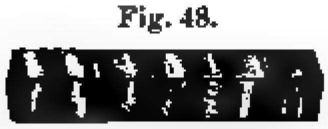


Fig. 49.

black and greenish-black, common either in distinct, stout crystals, or fibrous; also in short and stout green crystals; also in long

green prisms and fibrous masses, when it is called *actinolite;* or in grayish and brownish-green fibrous or acicular forms, when it is called *anthophyllite;* also in long white prisms and fibrous masses, when it is called *tremolite;* also in short, thick, white prisms, called *white hornblende;* also in very delicately-fibrous masses, the fibres flexible like flax, when it is called *asbestus;* also in rock-masses made of coarse cleavable grains. Hardness nearly or quite that of feldspar. Hornblende rocks, very tough. Before the blowpipe, somewhat fusible. *Composition:* Silica, with magnesia, lime, protoxyd of iron (and sometimes protoxyd of manganese), with occasionally a little alumina. A *lime*-and-*magnesia* variety contains—Silica, 60.7, lime, 12.5, magnesia, 26.8; an *iron*-and-*magnesia* variety—Silica, 58.6, magnesia, 25.9, protoxyd of iron, 15.5.

(14.) Pyroxene (often called Augite).—In oblique prismatic crystals (monoclinic) of 87° 5′, and therefore nearly square, with cleavage parallel to the faces, often having all four edges replaced so as to make an eight-sided prism. In colors, hardness, specific gravity, and composition, like hornblende. Cleavable, massive kinds of a dingy grayish-green color are called *sahlite.* In volcanic rocks the crystals are black, rather small, and like figs. 50 and 51 in form; in metamorphic rocks they are usually grayish green, and often large and coarse. In serpentine *diallage* is common, and with labradorite *hypersthene* frequently occurs. Before the blowpipe, like hornblende; some foliated varieties infusible. *Composition:* The pale-green varieties contain—Silica, 55.7, magnesia, 18.5, lime, 25.8. Others of dark-green and black colors, Silica, 53.7, magnesia, 13.4, lime, 24.9, protoxyd of iron, 8.0; or, Silica, 48.6, lime, 22.5, protoxyd of iron, 28.9.

Fig. 50.

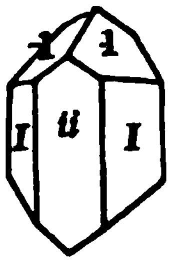
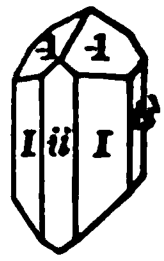


Fig. 51.



If *thin*-foliated, the brittle folia often partly separable, called *hypersthene* when brownish green or bronze-like, and *diallage* when grass-green.

(15.) Chrysolite.—In small grains disseminated through basaltic rocks and many lavas, also in imbedded masses and rectangular crystals. Appearance glassy, and often dark green like bottle-glass, (a variety called *olivine*): also pale green. Hardness nearly that of quartz. G. = 3.3–3.5. Infusible, excepting some kinds containing much iron. *Composition:* essentially a silicate of magnesia, or magnesia and iron; a common kind contains—Silica, 41, magnesia, 50, protoxyd of iron, 9.

(16.) Chondrodite.—In large and small grains or masses imbedded usually

in granular limestone. Color, pale yellow and brownish yellow. Brittle, without cleavage or much lustre. Hardness, as with chrysolite. G. = 3.1–3.24. *Composition:* nearly like chrysolite, but containing fluorine: Silica, 33, magnesia, 56, protoxyd of iron, 3, fluorine, 8.

3. *Protoxyd-Silicates containing water.*

66. (17.) TALC.—In foliated masses; folia flexible, but *not* elastic; also compact-massive, very soft, and having a greasy feel, either granular, or very compact without any appearance of grains, when it is called *soapstone* or *steatite*. G. = 2.5–2.8. Before the blowpipe, infusible. *Composition:* a silicate of magnesia; Silica, 62.12, magnesia, 32.94, water, 4.94.

(18.) SERPENTINE.—Usually massive, without cleavage or any granular texture, and soft enough to be scratched easily by a knife. Sometimes thin-foliated, with the folia brittle; also delicately fibrous, and then often called *amianthus* and *chrysotile*. Sometimes in rectangular and rhombic prisms. Color, dark to light green. Before the blowpipe, fuses with difficulty on thin edges. G. = 2.2–2.6. *Composition:* Silica, 43.6, magnesia, 43.4, water, 13.0.

(19.) CHLORITE.—Thin micaceous, like mica, but folia *not* elastic, and color olive-green, rarely whitish. Commonly massive, with a fine granular texture, and of massive varieties. Quite soft, so as to be cut easily with a knife. G. = 2.7–3. Before the blowpipe, more or less fusible. *Composition:* Silica, 27.2, alumina, 23.1, magnesia, 13.5, protoxyd of iron, 24.2, water, 12.1. This mineral contains alumina, like those of the following subdivision; but its magnesia gives it its character, and it is usually associated with other magnesian rocks.

Clinochlore and *ripidolite* are names of other chlorites. (See author's Mineralogy.)

4. *Alumina-Silicates containing water.*

67. (20.) AGALMATOLITE.—A compact material, resembling steatite, without any distinct grain, white or grayish in color, and easily cut with a knife. It is one of the kinds of materials cut into images in China. Specific gravity, 2.7–2.9. It is a silicate of alumina and potash, containing about 46 per cent. of silica, 32 of alumina, 8 of potash, and 7 per cent. of water, with traces of some other ingredients. The *Parophite* of Hunt is a rock of similar composition, from Canada; and the dysyntribite of Shepard is a related compound, from northern New York, of grayish green, brownish, and other shades of color. In the vicinity of the dysyntribite large hexagonal crystals have been found, resembling the *Gieseckite* of Greenland, and showing that gieseckite also belongs here, as ascertained by G. J. Brush. These crystals, and also the gieseckite, are supposed to be *altered nepheline.*

PYROPHYLLITE.—A mineral resembling talc in its appearance and soapy feel, but consisting of silica, 66, alumina, 29, water, 5. There is a massive waxy variety, which resembles the pagodite and some soapstone. The massive pyrophyllite differs from pagodite in containing no alkali and more silica. The preceding hydrous silicates of alumina have the soapy feel of talc, a hydrous silicate of magnesia, and by most persons would on first examination be pronounced magnesian. They are the basis of a slaty rock *much like talcose slate, but containing no magnesia*,—a point of interest to the geological observer.

68. (21.) ZEOLITES and *related minerals*.—The zeolites are hydrous minerals, consisting of silica and alumina, with lime or an alkali. They resemble the feldspars closely in composition, but contain water, are less hard and more fusible. They occur in cavities and veins in igneous rocks, or disseminated through the mass of the rocks; also in cavities in granite and some other feldspathic rocks. The following are the more prominent:—

a. Analcime: occurs in trapezohedral crystals, glassy and clear, or white. Hardness a little less than that of feldspar.

b. Chabazite: in rhombohedral crystals, nearly cubic, white and reddish.

c. Natrolite: in fibrous masses and acicular crystals, usually white, without a pearly cleavage. *Scolecite* closely resembles natrolite.

d. Stilbite: in flattened prisms with dihedral summits, and having a broad, pearly cleavage-surface parallel to one face of the prism; prisms often grouped into sheath-like forms, and usually white.

e. Heulandite: in rhomboidal prisms, with pearly basal cleavage, often transparent, and usually white.

Composition:

Analcime =	Silica, 54.6,	Alumina, 23.2,	Soda, 14.0,	Water, 8.1.
Chabazite	" 48.2,	" 20.0,	Lime, 10.8,	" 21.0.
Natrolite	" 47.4,	" 26.9,	Soda, 16.2,	" 9.5.
Scolecite	" 46.0,	" 26.1,	Lime, 14.2,	" 13.7.
Stilbite	" 57.6,	" 16.3,	" 8.9,	" 16.3.
Heulandite	" 59.3,	" 16.8,	" 9.2,	" 14.7.

They resemble the feldspars in having the same ratios between the protoxyds, sesquioxyds, and silica, this ratio being—in Heulandite 1:1:4; in Stilbite 1:1:3; in Natrolite 1:1:2; in Chabazite 1:1:2⅔; in Analcime 1:1:2⅔.

f. PREHNITE is a species related to the zeolites, and similar in its modes of occurrence. It is harder, the hardness being that of feldspar. The surface is usually clustered, convex, and crystalline; the color, pale green to white; translucent. G. = 2.8–3.0. Before the blowpipe, intumesces and melts. *Composition:* Silica, 43.8, alumina, 24.8, lime, 27.1, water, 4.3.

5. *Carbonates. Sulphates.*

69. (22.) CALCITE, or *Carbonate of Lime*.—Crystals rhombohedral or hexagonal, with perfect cleavage parallel to the faces of a rhombohedron the obtuse angle between whose faces (or R on R, fig. 52 A) is 105° 5′. Forms various, a few of which are shown in the figures. Crystals often transparent; massive kinds granular, as in statuary marble, or opaque and earthy, as in common limestones. Colors,

from white to yellowish, reddish; grayish-brown to black when impure. Easily scratched with a knife. G. = 2.5–2.8. Crystalline

Fig. 52.

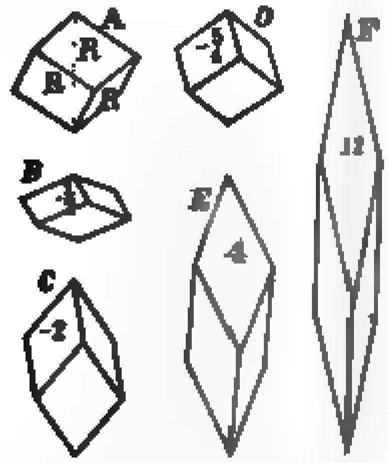
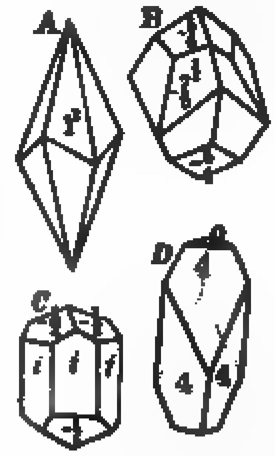


Fig. 53.



varieties readily distinguished by the angle, 105° 5′, between the cleavage-faces; and all kinds by the low degree of hardness, ready effervescence when touched with a drop of dilute muriatic acid, and infusibility. When burnt, it becomes quicklime. *Composition:* Carbonic acid, 44.0, lime, 56.0.

The same compound, carbonate of lime, occurs under a prismatic crystalline form, and is then called *Aragonite:* it is easily recognized by the absence of the rhombohedral cleavage, and also by means of polarized light. It is somewhat harder than calcite. G. = 2.9–3.0. In shells the pearly part is Aragonite, while the rest is usually calcite.

(23.) Magnesite.—Crystals rhombohedral or hexagonal, like calcite, with the angle between two planes R 107° 29′: but usually massive, and often looking like porcelain biscuit. Harder than calcite. Color, white. G. = 2.8–3. Infusible: no immediate effervescence when touched with dilute acid, though dissolving when powdered and heated with acid. *Composition:* Carbonic acid, 52.4, magnesia, 47.6.

(24.) Dolomite.—Rhombohedral, as in calcite, with R on R = 106° 15′. Also massive, constituting much of the white architectural marble, and some earthy limestones. G. = 2.8–3.0. Distinguished from calcite by not affording effervescence when touched with dilute acid, unless heated. It is a carbonate of magnesia and lime, containing carbonate of lime, 54.4, carbonate of magnesia, 45.6.

(25.) Chalybite.—A carbonate of the protoxyd of iron, having the same crystallization as carbonate of lime or calcite, but higher specific gravity (G. = 3.7–3.9), somewhat greater hardness, and a grayish or brownish color becoming deep brown on exposure.

70. (26.) Gypsum.—Crystals as in the figures 54 and 55, an oblique (monoclinic) prism, with very perfect cleavage in one direction, affording large pearly plates, which bend in one direction and

break in another, and are inelastic. Also fibrous, with satin lustre. Also earthy, massive, of dull gray and other colors. Very soft, so as easily to be cut with a knife. The white, compact kind is alabaster. When heated, burns white and crumbles, losing its water, and becoming a powder, which is common "plaster of Paris." *Composition:* Sulphuric acid, 46.51, lime, 32.56, water, 20.93.

Fig. 54.

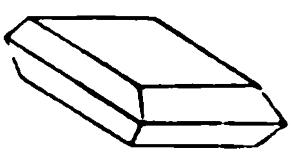
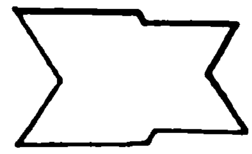


Fig. 55.

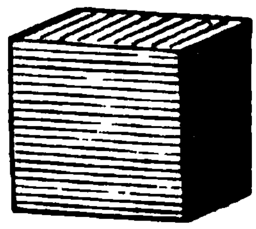


(27.) ANHYDRITE.—The same in composition as gypsum, except that it contains no water. Crystals rectangular, with three distinct and nearly equal cleavages, affording cubical and rectangular blocks, and thus easily distinguished from those of gypsum. Color, white, grayish, bluish, and other pale shades. Hardness near that of calcite. G. = 2.8–3.01. Before the blowpipe, does not exfoliate like gypsum. *Composition:* Sulphuric acid, 58.8, lime, 41.2.

6. *Additional mineral species.*

71. (28.) GRAPHITE, called also Plumbago or Black Lead. The lustre, softness, and the tracing it leaves are well seen in the common "lead-pencil." The structure is either foliated or granular; and sometimes it gives a slaty structure to a rock. It is essentially pure carbon.

Fig. 56.



(29.) PYRITES (Iron Pyrites).—In cubes, the adjacent faces of which are often striated at right angles with one another, as in the annexed figure (56); also in other forms; also massive. Color, pale brass-yellow. Hard enough to strike fire with steel. G. = 4.8–5.1. *Composition:* Sulphur, 53.3, iron, 46.7.

(30.) CHALCOPYRITE (or Copper Pyrites).—Resembles iron pyrites, but is of a deeper yellow color, much softer, being scratched with a knife, and giving a dark-greenish powder, and when wet with nitric acid a knife-blade put in the acid becomes coated with copper. Contains sulphur, 34.9, copper, 34.6, iron, 30.5. There is also a *gray* sulphuret of copper, called *copper-glance*, which has a steel or iron lustre, and consists of sulphur, 20.2, copper, 79.8. There is still another, which tarnishes readily, and is sometimes called horse-flesh ore, from the color of the tarnish, which consists of sulphur, 23.7, copper, 62.5, iron, 13.8.

(31.) BLENDE.—In crystals; also massive, cleavable, with a brilliant lustre; the lustre resinous; the yellow and brown varieties look much like a resin, and the black variety approaches metallic in lustre; a touch of the point of a knife affords a white or whitish scratch or powder. Blende is a sulphuret of zinc, containing sulphur 33, zinc 67.

(32.) GALENA.—In cubic and other related crystalline forms, and breaking readily by cleavage into small cubes; also massive and granular. Color, lead-gray. Readily cut by a knife, although brittle. G. = 7.2–7.7. Galena is the common lead-ore, a sulphuret of lead, consisting of sulphur, 13.4, lead, 86.6.

72. (33.) HEMATITE (or Specular Iron). A common iron-ore, having often a high metallic lustre, though often also red and earthy. Powder deep red or brownish red. Not attracted by the magnet. As hard as feldspar. *Composition:* Oxygen, 30, iron, 70. *Titanic iron* (Ilmenite) resembles hematite closely, but has a black powder, and contains titanium with the iron.

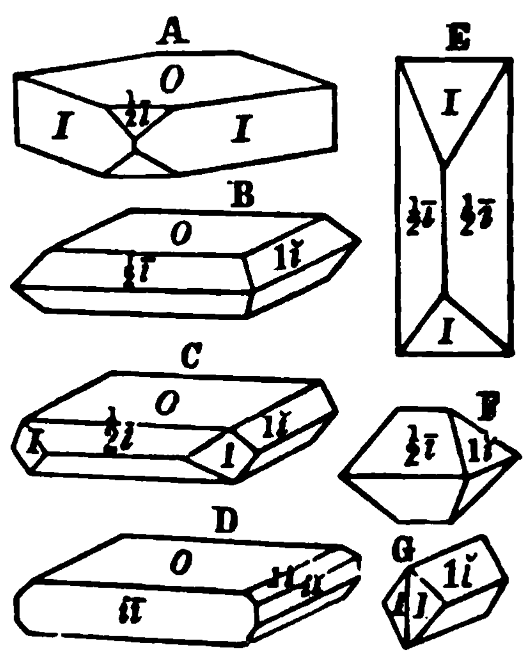
(34.) MAGNETITE (or Magnetic Iron-Ore). Crystals octahedrons, and sometimes cubes or dodecahedrons. Iron-black. *Powder black.* Strongly attracted by a magnet. G. = 4.9–5.2. *Composition:* Protoxyd of iron, 31.03, peroxyd of iron, 68.97; or, Oxygen, 27.6, iron, 72.4.

(35.) LIMONITE (Hydrous Sesquioxyd of Iron).—In massive forms; often also stalactitic and mamillary; black and imperfectly metallic in lustre, or brown to yellowish-brown, and earthy. *Powder yellowish-brown.* G. = 3.6–4. *Composition:* Sesquioxyd of iron, 85.6, water, 14.4; or the same as hematite, excepting the water. The color of the powder distinguishes this species, as well as the magnetite, from hematite.

HEMATITE, *Magnetite*, and *Limonite* are the three most common ores of iron. They are distinguished by the color of their powders.

73. (36.) FLUOR SPAR (Fluorid of Calcium). In cubes, octahedrons, and other forms, with a perfect and easy cleavage on the angles of the cube; also massive, granular. Often transparent and glassy; also translucent. Colors, clear and handsome, blue, purple, yellow, reddish, white; sometimes banded; receiving a high lustre when polished. When powdered coarsely and thrown on a shovel heated to just below redness, it phosphoresces finely. Heated with sulphuric acid, it gives out vapors which corrode glass. *Composition:* Fluorine, 48.7, calcium, 51.3.

Fig. 57.



(37.) BARYTES (or Heavy Spar, Sulphate of Baryta). In tabular crystals (fig. 57), rectangular or rhombic. Color, white, sometimes yellowish, reddish. Remarkable for its weight. G. = 4.3–4.7. *Composition:* a sulphate of baryta = Sulphuric acid, 34.33, baryta, 65.67.

(38.) APATITE (Phosphate of Lime).—In hexagonal prisms, often large; no good cleavage; also massive. Color, sea-green, bluish- to yellowish-white, often resembling beryl, but much softer, being scratched with the point of a knife. Transparent to opaque. G. = 3.25. *Composition:* Phosphoric acid, 42.26, lime, 50.0, fluorine, 3.77, calcium, 3.97.

(39.) CLAY.—*Clay* is not a simple mineral. It is the material of such rocks as contain feldspar, ground up to an impalpable powder. It is therefore often a mixture of finely-ground feldspar and quartz, in which the former predominates, together usually with other ingredients derived from the rocks, as lime, magnesia, and oxyd of iron, in small or large proportions. Clay, when baked, makes brick or pottery; and, if it contains oxyd of iron, it burns red, the oxyd of iron losing in the process the water which was in combination with it.

Clays which have a peculiar unctuous feel are more or less pure chemical compounds, consisting of silica, alumina, and water, and related to the mineral species *Halloysite*. Halloysite consists of silica, 41.5, alumina, 34.4, water, 24.1. It results from the decomposition of feldspar. *Kaolin*, or *porcelain clay*, is another product of the decomposition of feldspar, consisting usually of silica, 45, alumina, 40, water, 15. It is a fine white clay, and is used for the finest porcelain. Potter's clay contains more or less of these ingredients, kaolin, halloysite, or the allied species.

7. *Materials of organic origin.*

74. The materials of organic origin—that is, those derived from plants or animals—may be arranged in *four* groups.

(1.) The *calcareous*, or those of which limestones have been formed: namely, corals, corallines, shells, crinoids, etc. The specific gravity of corals is 2.4–2.82; of shells, 2.4–2.86,—the highest from a Chama (Silliman, Jr.).

(2.) The *siliceous*, or those which have contributed to the silica of rocks, and may have originated flints, namely, (*a*) the microscopic siliceous shields of the infusoria called *diatoms*, which are now regarded as plants; (*b*) the microscopic siliceous spicula of sponges.

(3.) The *phosphatic*, or those which have contributed phosphates, especially the phosphate of lime, as *bones*, *excrements*, and a few shells related to the *Lingula*. Fossil excrements are called *coprolites*; or those of birds when in large accumulations, *guano*.

The remains of animals have also afforded traces of fluorine.

(4.) The *carbonaceous*, or those which have afforded coal and resin, as plants.

Besides these, there is a fifth kind, though of little importance geologically, viz., the animal tissues themselves. Only in a few cases do any of these tissues remain in fossils, except in some kinds of the later geological epochs. These tissues contain traces of phosphates and fluorids.

75. (1.) CALCAREOUS.—The following are a few analyses: 1 and 2, corals, Madrepora palmata and Astræa Orion, by B. Silliman, Jr.; 3, a shell, by the same:—

	Madrepore.	Astræa.	Shell (Chama).	Oyster-shell.
Carbonate of lime.........	94.81	96.47	97.00	93.9
Phosphate and fluorids.	0.45	0.06	2.60	0.5
Sulphate of lime..........	......	......		1.4
Earthy matters............	0.30	0.74		
Organic tissues............	4.45	2.73	0.40	3.9
Carbonate of magnesia..	......	......	......	0.3

In many shells the inner pearly layer consists of carbonate of lime in the condition of Aragonite (§ 69); while the outer (or the whole, if no part is pearly) is usually common carbonate of lime, or calcite. The spines of *Echini* are calcite.

In corals of the genus *Millepora*, according to Damour, there is, besides carbonate of lime, some carbonate of magnesia, amounting in one species to 19 per cent., while but little in others. These corals have been shown by Agassiz to be related to the *Medusæ*, and not to the ordinary polyps. Forchhammer found 6.36 per cent. of carbonate of magnesia in the *Isis nobilis*, and 2.1 per cent in the *Corallium nobile*, or precious coral of the Mediterranean.

The *Nullipores* and *Corallines* are vegetation having the power of secreting lime, like the coral animals. The shells of *Rhizopods* (called also *Polythalamia* and *Foraminifera*) are calcareous.

The shell of a lobster (Palinurus) afforded Fremy, Carbonate of lime, 49.0, phosphate of lime, 6.7, organic substance, 44.3.

76. (2.) Siliceous.—The organic Silica is, in part at least, in that condition characterizing opal (p.55.) The mineral Randanite is a kind of opal, made of infusorial remains.

77. (3.) Phosphatic.—Analyses of *bones:* 1, 2, human bones, according to Frerichs: 3, fish (Haddock), according to Dumenil; 4, shark (Squalus cornubicus), according to Marchand; 5, *fossil* bear, id.

	1.	2.	3.	4.	5.
Phosphate of lime	50.24	59.50	55.26	32.46	62.11
Carbonate of lime	11.70	9.46	6.16	4.44	13.24
Sulphate of lime	......	......	......		12 25
Organic substance	38.22	30.94	37.63	58.07	4.20
Traces of soda, etc.	......	......	1.22	3.80	......
Fluorid of calcium	......	......	......	1.20	2.12
Phosphate of magnesia	......	......	......	1.03	0.50

In No. 4 a little silica and alumina are included with the fluorid. No. 5 contains also silica 2.12, and oxyds of iron and manganese, etc., 3.46.

The *enamel* of teeth contains 85 to 90 per cent. of phosphate of lime, 2 to 5 of carbonate of lime, and 5 to 10 of organic matters.

Fish-scales from a Lepidosteus afforded Fremy 40 per cent. of organic substance, 51.8 of phosphate of lime, 7.6 of phosphate of magnesia, and 4.0 of phosphate of lime. Other fish-scales contained but a trace of the magnesia-phosphate and more of organic matters.

Phosphatic nodules, possibly coprolitic, in the Lower Silurian rocks of Canada (on river Ouelle) afforded T. S. Hunt (see Am. Jour. Sci. [2] xv. and xvii.), in one case, phosphate of lime, 40.34, carbonate of lime, with fluorid, 5.14, carbonate of magnesia, 9.70, peroxyd of iron, with a little alumina, 12.62, sand, 25.44, moisture, 2.13 = 95.37. In a hollow cylindrical body from the same region there were 67.53 per cent. of phosphate.

Analyses of Coprolites (*fossil excrements*).—Nos. 1 and 2 by Gregory and Walker; 3 and 4 by Connell; 5 by Quadrat; 6 by Rochleder (a coprolite from the Permian).

	1. Burdiehouse.	2. Fifeshire.	3. Burdiehouse.	4. Burdiehouse.	5. Koechtitz.	6. Oberlangenau.
Phosphate of lime	9.58	63.60	85.08	83.31	50.89	15.25
Carbonate of lime	61.00	24.25	10.78	15.11	32.22	4.57
Carbonate of magnesia	13.57	2.89	......	......	......	2.75
Sesquioxyd of iron	6.40	*trace*	......	......	2.08	......
Alumina	......	......	......	......	6.42	......
Silica } Organic material }	4.13	*trace*	0.34	0.29	0.14	......
Organic material		3.38	3.95	1.47	7.38	74.03
Water	5.33	3.33	......	......	......	......
Lime of organic part	......	......	......	......	......	1.44
Chlorid of sodium	......	......	......	......	......	1.96
	100.01	97.45	100.15	100.18	99.13	100.00

Analysis of the shell of the recent *Lingula ovalis*, according to T. S. Hunt (Am. Jour. Sci. [2] xvii. 237):—Phosphate of lime, 85.79, carbonate of lime, 11.75, magnesia, 2.80 = 100.34,—or very near the composition of bones. The shell of species of Orbicula and Conularia was found to have the same composition.

78. (4.) CARBONACEOUS.—*Mineral coal* is essentially carbon, combined usually with bitumen or some kind of bituminous substance, and more or less earthy substance (the *ash*). The varieties are—

A. *Anthracite.*—Containing no bituminous matter. A hard, lustrous coal, breaking with a conchoidal fracture and clean surface, and burning with very little flame, as the coal of Lehigh, Wyoming, and other places of central Pennsylvania, also that of Rhode Island.

B. *Bituminous coal.*—Containing bituminous substances, and therefore burning with a bright flame. Softer than anthracite, less lustrous, often looking a little pitchy. The amount of bituminous substances varies from 10 to 60 per cent., and occasionally reaches 72 per cent. Among the kinds of bituminous coal there are—

a. Caking Coal. The common variety when caking in the fire from the exuding bitumen.

b. Cannel Coal. A very compact coal, with an even texture, smooth, clean, and nearly dull surface, and a conchoidal fracture. The dull lustre gives it the aspect often of being impure, when not so. The proportion of bitumen is large.

c. Asphaltic Coal. A black and very lustrous coal, looking like pure asphaltum or mineral pitch. From the Albert mine, Nova Scotia. Four per cent. soluble in ether, and thirty in turpentine.

C. *Lignite* is a black or brownish-black coal, having an empyreumatic odor when burned, and usually retaining something of the texture of the original wood. It is sometimes called *brown coal.* It belongs to secondary and more modern deposits. *Jet* is a very compact, black, and lustrous lignite. *Peat* is an imperfect coal, made mainly from mosses in swamps after a long burial and a partial alteration of the material. It is sometimes entirely converted into coal.

The composition of mineral coal varies much. The following are the results of some analyses :—

	Volatile combustible matter.	Fixed carbon.	Ash.		
Anthracites of Pennsylvania.........	3.84	87.45	7.37 =	98.66	Johnson.
Bituminous, Pittsburg.....................	32.95	64.72	2.31 =	99.98	Johnson.
" La Salle, Illinois.......	39.17	54.19	6.64 =	100	Whitney.
Cannel, Boghead, Scotland	66.35	30.88	2.77 =	100	Silliman.
" Breckenridge co., Kentucky	55.7–71.7	28.3–44.3	7.–12.30		Peter.
" Wigan, Lancashire, England	50.18	46.42	3.40 =	100	Heddle.
Asphaltic coal..........................	61.74	36.04	2.22 =	100	Silliman.

Ultimate analyses, to determine the proportions of the elements, have given—the ashes excluded—

	Carbon.	Hydrogen.	Oxygen.	Nitrogen.	
Anthracite.....................	94.05	1.75	4.20	0.00	Regnault.
Bituminous..................	82.2	5.5	12.3	0.00	Bischof.
Cannel, Boghead..........	80.49	11.24	6.73	0.87	Peter.
Cannel, Breckenridge ...	82.36	7.84	7.05	2.75	Peter.
Asphaltic coal	82.67	9.14	8.19		Wetherill.
Lignite.........................	72.3	5.3	22.4		Regnault.
Peat, Provincetown......	60.1	6.1	33.8		Vaux.
Peat coal, Westphalia...	80.7	4.1	15.2		Baer.

The ashes consist mostly of silica and alumina, in the ratio of 1 of the former to 1 or 2 of the latter, with a trace of lime and magnesia; and, in those coals which afford a red ash, some oxyd of iron, often derived from pyrites mixed with the coal. In good coals, the ash does not exceed 10 per cent., of which, as an average, 2 to 4 might be silica, 4 to 7 alumina, and ½ each lime and magnesia, or oxyd of iron.

Resins of several kinds occur in some coal-beds, especially in those of tertiary age. *Amber* is of this kind. They come from the ancient trees, but have been altered in the course of their long burial.

Fossils.—From the above account of the composition of the hard parts of organic beings, their influence on the composition of rocks is readily inferred.

But the fossils themselves seldom retain completely, even in the case of such stony secretions as shells and corals, their original constitution. There is usually a loss of the organic matter. There is often a further change of the carbonate of lime into a new molecular condition, manifest in the fact that the fossil has the oblique cleavage of calcite; and in this change there is a loss of part or all of the phosphate or fluorid. There is sometimes, again, a change to dolomite, in which the carbonate of lime becomes a carbonate of lime and magnesia. In other cases, of very common occurrence, all the fossils of a rock, whether limestone or sandstone, are changed

to silica (quartz) by a silicifying process. Silicified trunks of trees, as well as shells, occur of all geological ages. In some cases fossils have been altered to an oxyd of iron, or to the sulphuret of iron (pyrites).

In many cases the fossils are entirely dissolved out by percolating waters, leaving the rock full of cavities. This happens especially in sandstones, through which waters percolate easily, and not in clays, which preserve well the fossils committed to them; and hence sands, gravel, conglomerates, quartzose sandstones, contain few organic remains.

3. KINDS OF ROCKS.

79. **General subdivisions.**—Rocks are conveniently divided into *fragmental* and *crystalline*.

1. *Fragmental.*—Rocks that are made up of pebbles, sand, or clay, either deposited as the sediment of moving waters or formed and accumulated through other means:—as ordinary *conglomerates*, *sandstones*, *clay-rocks*, *tufas*, and some *limestones*. The larger part of the rocks here included are made of sedimentary material, and are commonly called *sedimentary* rocks. They are *stratified* rocks,—that is, consist of layers spread out one over another. Many of them are *fossiliferous* rocks, or contain fossils.

2. *Crystalline.*—Rocks that have a crystalline instead of a fragmental character. The grains, when large enough to be visible, are crystalline grains, and not water-worn particles or fragments of other rocks. Examples, granite, mica schist, basalt.

The crystalline rocks may have been crystallized,—

a. From fusion, like lava or basalt, when they are called *igneous rocks*.

b. From solution, as with some limestones.

c. Through long-continued heat without fusion. By this last method sedimentary beds have been altered into granite, gneiss, or mica schist, and compact limestone into statuary-marble.

As, in such cases, a bed originally sedimentary has been metamorphosed into a crystalline one, rocks of this altered kind are called *metamorphic rocks*.

In the following descriptions a separate subdivision is made of the *calcareous* rocks or *limestones*, which are mostly sedimentary in original accumulation, but generally lose that appearance as they solidify.

80. **Characteristics of Rocks.**—Independently of the characters above mentioned, rocks differ in kinds:—

a. First. As to STRUCTURE: whether—

Massive, like sandstone, or granite, breaking one way about as easily as another.

Schistose or *laminated*, breaking into slabs, like flagging-stone; *schistose* is usually restricted to the crystalline rocks, like gneiss and mica schist.

Slaty, breaking into thin and even plates, like roofing-slate.

Shaly, breaking unevenly into plates, and fragile, like the slate or shale of the coal formation, the Utica slate, etc.

Concretionary, having the form of, or containing, spheroidal concretions; some varieties are also called *globuliferous*, when the concretions are isolated globules and evenly distributed through the texture of a rock.

b. Second. As to HARDNESS and FIRMNESS:

Compact, or well consolidated.

Friable, or crumbling in the fingers.

Porous, so loose or open in texture as to absorb moisture readily.

Uncompacted, or like loose earth.

Flinty, very hard, and breaking with a smooth surface like flint.

c. Third. As to the ROCK OR MINERAL NATURE of the constituents:

Granitic, like granite, or made of granite materials.

Siliceous, consisting mainly of quartz.

Quartzose, same as siliceous; but also consisting largely of quartz in grains, —a quality expressed by *arenaceous*, when the rock is mainly made up of quartz grains.

Micaceous, characterized eminently by the presence of mica.

Calcareous, of the nature of limestone, or containing considerable carbonate of lime, as a calcareous rock, a calcareous mica schist.

Argillaceous, having a clayey nature or constitution, or containing much clay, as shale is argillaceous, a sandstone may be argillaceous.

Ferruginous, containing oxyd of iron; sometimes having a red, brownish-red, or brownish-yellow color in consequence of the disseminated oxyd of iron; sometimes containing the ore in plates or masses of a metallic lustre.

Pyritiferous, containing pyrites (p. 64) disseminated through the mass, either in cubic crystals, or in grains or masses.

Basaltic, made of material derived from basalt; also like basalt.

Pumiceous, made of pumice.

Garnetiferous, containing garnets.

So, also, *staurotidiferous*, containing staurotide; *anthophyllitic*, containing acicular hornblende of the variety anthophyllite.

Sedimentary rocks differ, further (*d*), as to the mechanical condition of the constituents: whether—

(*a*) *Rounded stones* or *pebbles*; or (*b*) *angular stones*; or (*c*) *sand*; or (*d*) *clay*.

Crystalline rocks differ, further,—

e. As to the number and kinds of *mineral constituents*, as explained beyond.

f. As to the kind of crystalline aggregation or structure:

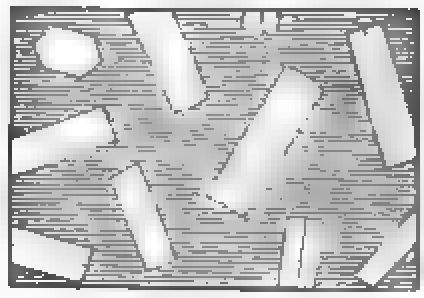
Granular (*phanero-crystalline*, or distinctly crystalline), which may be either *coarse granular*, as in granite and much architectural marble, or *fine granular*, as in some statuary-marble.

Cryptocrystalline, or concealed crystalline, as in flint, no particles being distinct.

Granitoid, having each of the mineral constituents separately crystallized and distinct, as in granite, syenite, diorite.

Other terms bearing on structure are as follow:—

Fig. 58.



Porphyritic.—Having the feldspar in distinct crystals through the mass of the rock, or speckling it with spots of white or a light color that are often rectangular or nearly so (fig. 58).

The term *porphyritic* is sometimes applied also where hornblende or pyroxene is in distinct crystals in the rock-mass, the rock in this case being described as porphyritic with hornblende or with pyroxene.

The feldspar crystals are often double or twin crystals, as shown by a line of division through the middle (see fig 58). Granite, diorite, dolerite, and lavas, as well as porphyry, are sometimes porphyritic, and the feldspar crystals might be very large or very small.

Homogeneous, having the mineral ingredients not separately distinguishable, but forming a homogeneous mass, granular or otherwise, like most trap, or dolerite and argillite.

Amygdaloidal (from *amygdalum*, an almond). Having numerous spheroidal or almond-shaped cavities, like some trap, dolerite, basalt, the cavities filled with minerals foreign to the rock, such as quartz, calcite, and the zeolites.

Scoriaceous.—Slag-like, very open, cellular, or inflated, like the scoria of a volcano or slag of a furnace.

It should further be observed that a rock—

When *Quartz* predominates, is *hard and often gritty*. G. = 2.5–2.8.

Feldspar—hard, usually light-colored. G. = 2.5–2.8. Either cleavably crystalline or cryptocrystalline.

Hornblende and *Pyroxene*—hard, usually dark-green to black; heavy. G. = 2.8–3.6. Often tough.

Mica—slaty, glistening with mica scales, not very hard, not greasy to the touch. G. = 2.5–2.8.

Talc—often slaty, somewhat glistening, a greenish color, grayish, brownish, not very hard; a *greasy feel*. G. = 2.4–2.7.

Chlorite—often slaty, soft, an *olive-green* color; but little greasy to the touch. G. = 2.7–3.2.

Serpentine—massive, rather soft, dark or light green; but little greasy to the touch. G. = 2.4–2.6.

Carbonate of lime—moderately soft, effervescing readily with acids. G. = 2.5–2.8. Usually massive; white to black.

Carbonate of lime and magnesia, or dolomite—like the preceding; but not effervescing readily with cold acid.

An easy effervescence with dilute muriatic acid indicates the presence of carbonate of lime.

1. Fragmental Rocks, exclusive of Limestones.

81. (1.) CONGLOMERATE.—A rock made up of pebbles or fragments of rocks of any kind. (*a*) If the pebbles are rounded, the conglomerate is a *pudding-stone*; (*b*) if angular, a *breccia*.

Conglomerates are named, according to their constituents, *siliceous* or *quartzose*, *granitic*, *calcareous*, *porphyritic*, *pumiceous*, etc., using these terms as already explained. The cementing-ingredient may be *calcareous*, *siliceous*, *ferruginous*, and occasionally of other kinds.

(2.) GRIT, GRIT-ROCK.—A hard, gritty rock, consisting of sand and small pebbles, called also *millstone grit* and *grindstone grit*, because used sometimes for grindstones. Also applied to a hard, gritty sandstone, as the paving-stone of the Hudson River.

(3.) SANDSTONE.—A rock made from sand agglutinated. There are *siliceous*, *granitic*, *porphyritic*, *basaltic*, or *calcareous* sandstones, according to the nature of the material. But the *calcareous* is called *calcareous sand-rock* rather than sandstone. There are also *compact sandstone*, *friable sandstone*, *ferruginous sandstone*, *concretionary sandstone*.

Micaceous sandstone.—A sandstone glistening with scales of mica.

Argillaceous sandstone.—Containing much clay with the sand; also called *shaly sandstone*, when thin-laminated in structure.

Marly sandstone.—Containing carbonate of lime, so as to effervesce when treated with dilute acid.

Flexible sandstone.—See Itacolumite, § 88.

(4.) SHALE.—A soft, fragile rock, made from clay, and having an uneven slaty structure as explained on page 71. Shales are gray to black in color, and sometimes of dull greenish, purplish, reddish, and other shades.

Among the varieties there are—

Bituminous shale.—Impregnated with bitumen, or yielding the odor of bitumen when struck.

Coaly shale.—Containing coaly impressions or impregnations.

Alum shale.—Impregnated with alum or pyrites,—usually a crumbling rock. The alum proceeds from the alteration of pyrites.

(5.) TUFA. POZZUOLANA.—*Tufa* is an earthy rock, not very hard, made from comminuted volcanic rocks, or volcanic cinder, more or less decomposed, and often forming beds of great extent. It is usually of a yellowish-brown, gray, or brown color.

The color varies with the nature of the material:—basaltic rocks or lavas produce brownish colors (the color is owing to the hydrous oxyd of iron present, derived from the pyroxene or magnetic iron of the original rock, altered by the action of water); feldspathic lavas produce light-grayish colors. *Pumiceous tufa*, which belongs to the latter division, consists mainly of pumice in grains and fragments, more or less altered.

Pozzuolana is a kind of light-colored tufa, found in Italy, near Rome and elsewhere, and used for making an hydraulic cement.

WACKE.—An earthy, dark-brownish rock, resembling an earthy trap or dolerite, and usually made up of trappean or doleritic material compacted into a rock which is rather soft.

(6.) SAND. GRAVEL.—*Sand* is comminuted rock of any kind; but common sand is mainly comminuted quartz, or quartz and feldspar, while *gravel* is the same mixed with pebbles or stones. Occasionally sand contains scales of mica and has a glistening lustre. *Volcanic sand*, or *peperino*, is sand of volcanic origin, either the "*cinders*" or "*ashes*" (comminuted lava) formed by the process of ejection, or from lava rocks otherwise comminuted.

(7.) ALLUVIUM. SILT. TILL.—*Alluvium* is the earthy deposit made by running streams, especially during times of flood. It constitutes the flats on either side of the stream, and is usually in thin layers, varying in fineness or coarseness, being the result of successive depositions. *Silt* is the same material deposited in bays or harbors, where it forms the muddy bottoms and shores. *Till* is an earthy deposit, coarse or fine, following the courses of valleys or streams, like alluvium, but without division into thin layers, although in very thick deposits. The *till* of the Alpine valleys is formed by the action of glaciers. *Detritus* (from the Latin for *worn*) is a general term applied to earth, sand, alluvium, and the like.

2. Metamorphic or Crystalline Rocks, not Calcareous.

82. Metamorphic rocks are made from the sedimentary rocks above enumerated by some crystallizing process, and vary exceedingly in the perfection of the crystallization they have undergone. Granite stands at one end of the series, and hard sandstones called

quartzite, hard slates like roofing-slate, and partially crystallized limestones, at the other; so that a distinct line between them and the sedimentary beds cannot always be drawn. They are sometimes called *plutonic* rocks, to distinguish them from the true igneous rocks.

The common ingredients are *quartz*, *feldspar* of different kinds, *mica*, *hornblende*, *pyroxene*, *talc*, *epidote*, *chlorite*, *serpentine*; to which *garnet*, *andalusite*, *staurotide*, *tourmaline*, *topaz*, *graphite*, may be added as characterizing a number of varieties. The rocks are aggregates in general of two or more of the above-mentioned minerals; and, as the proportions may vary indefinitely, the kinds of rocks are not in all cases well defined; they graduate into one another through imperceptible shades.

Metamorphic rocks may, for the most part, be distributed into three series parallel with one another. These are the *mica-bearing* series, containing granite, gneiss, mica schist, etc.; the *hornblendic*, characterized by the presence of hornblende or the allied pyroxene, as in syenite, hornblendic gneiss, etc.; and the *hydrous magnesian* series, containing talc, chlorite, and serpentine rocks. Besides these, there are other groups, which with the foregoing are described beyond in the following order:—

1. Mica-bearing series.
2. Hornblendic series.
3. Feldspathic, epidotic, and garnet rocks, having the mass or body of the rock compact (cryptocrystalline).
4. Hydrous magnesian series.
5. Hydrous aluminous series, or rocks consisting essentially of agalmatolite or pyrophyllite.
6. Quartz rocks.
7. Iron-ore rocks.

1. *The Mica-bearing Series.*

The mica-bearing series commences with granite, the most highly crystalline, and descends through gneiss and mica schist to *argillite* or roofing-slate, and also to *quartzite*, which is but little removed from a sandstone. Quartz is a constant ingredient, as well as mica. The series branches off into crystalline feldspathic rocks like granulite, containing little or no mica. The specific gravity is between 2.4 and 2.8.

83. (1.) Granite.—A granular crystalline rock, consisting of quartz, feldspar, and mica, having no appearance of layers in the arrangement of the mica or other ingredients. The *mica* is in scales, usually white, black, or brownish, easily separable into thinner elastic scales by means of the point of a knife; the *quartz*

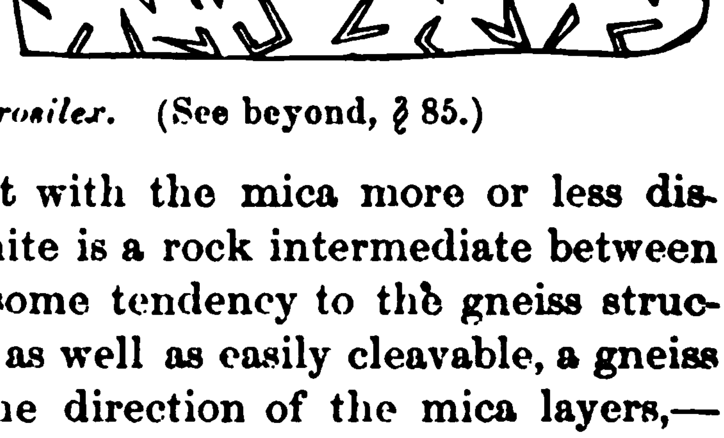
is usually grayish white, glassy, and *without any appearance of cleavage;* the *feldspar* is commonly whitish or flesh-colored, less glassy than the quartz, and showing a flat, polished cleavage-surface in one or two directions.

a. Common Granite.—A granite in which the feldspar is common feldspar (the species orthoclase, § 55), or potash-feldspar, the most common kind. The color is grayish or flesh-colored, according as this feldspar is white or reddish. The texture varies from a fine and even-grained to a *coarse granite* in which the mica, feldspar, and quartz—especially the two former—are in large crystalline masses. *Porphyritic granite* has the feldspar distributed in distinct crystals, which appear as rectangular whitish blotches on a surface of fracture. *Syenitic granite* contains black scales or grains of hornblende besides the mica. *Miascite* consists of cleavable white feldspar (orthoclase), black mica, and *grayish or yellowish-white elæolite,* with some hornblende, and occasionally albite or quartz. It is associated with syenite.

b. Albitic Granite.—A granite in which part or all of the feldspar is *albite,* or soda-feldspar (§ 55, *b*). This feldspar is usually white, and when both albite and orthoclase are present, the latter may often be distinguished by having a more grayish or reddish color, and by not having the cleavage-surface finely striated in one direction, like albite.

(2.) Pegmatite, or *Graphic Granite.*—A very coarse granitic rock, consisting of common feldspar and quartz with but little whitish mica; in the graphic variety the quartz is distributed through the feldspar in forms looking like Oriental characters (fig. 59).

Fig. 59.



(3.) Granulite. — A fine-grained granitic rock, consisting mainly of granular feldspar with little quartz, and often imperfectly schistose in structure from the arrangement of the quartz. It is also called *eurite* and *leptynite;* and the flinty kind, *petrosilex.* (See beyond, § 85.)

(4.) Gneiss.—Like granite, but with the mica more or less distinctly in layers. A *gneissoid* granite is a rock intermediate between granite and gneiss, or showing some tendency to the gneiss structure. As the mica is in scales as well as easily cleavable, a gneiss rock breaks most readily in the direction of the mica layers,—thus affording slabs. This structure, causing a tendency to break into slabs, is called a schistose structure.

Porphyritic Gneiss has distinct feldspar crystals disseminated through it, like porphyritic granite. Gneiss may abound in garnets, or be *garnetiferous;* or contain an excess of mica, when it is called *micaceous gneiss;* or much epidote, becoming an *epidotic gneiss.* Gneiss graduates into—

(5.) Mica Schist.—The same constituents as granite and gneiss,

but with less feldspar and much more mica,—therefore glistening in lustre; slaty, or very schistose, in structure, breaking into thin slabs or plates; often friable, or wearing easily.

Mica schist often abounds in garnets, staurotide (§ 61), or tourmaline (§ 63).

The variety *plumbaginous schist* contains plumbago (p. 64) in its layers. *Calcareous mica schist* contains, disseminated through it, carbonate of lime or calcite. *Talcose mica schist* contains talc as well as mica. *Hornblendic mica schist* contains black or greenish-black crystals of hornblende. *Anthophyllitic schist* is related to the last, but the acicular crystals are of the brown variety of hornblende called *anthophyllite*. *Concretionary mica schist* is a variety containing concretions: the concretions may consist of feldspar and contain garnets; or of mica and feldspar, etc. *Specular schist* is a variety in which the mica is replaced to a great extent by micaceous or lamellar specular iron. It may be connected either with mica schist or talcose schist.

(6.) Argillite, or Clay-Slate, Roofing-Slate.—Mica slate graduates into slates in which there is no distinct crystallization and even the mica is not apparent. This fine-grained slate-rock is ordinary roofing-slate and writing-slate, and occurs of bluish, purplish, red, and other colors, to black.

Argillite often contains andalusite (§ 60) running through it in prismatic crystals seldom smaller than a goose-quill, and one or more inches long. It also occasionally contains *garnet*, *tourmaline*, *staurotide*, and *ottrelite*,—the last a mica-like though brittle mineral, imbedded in small scales spangling the rock, as at Billingham, Massachusetts. The ottrelite has been called phyllite. The more glistening kinds of slate sometimes contain mica in distinct but minute scales, or have a sort of micaceous surface.

2. *Hornblendic Series.*

84. The hornblendic series commences in a granite-like species (called syenite) containing *quartz* and *feldspar* along with *hornblende* in place of mica. Hornblende is not so cleavable into leaves as mica, and is brittle instead of elastic. It is also tough and heavy; and hence hornblende rocks are generally tough and heavy, the specific gravity between 2.9 and 3.5. From *syenite* the series runs down through syenitic *gneiss* to hornblendic *schist* and hornblende rock; then to rocks of very even texture and compactness, called *diabase* and *aphanite*, the last like hornstone in fracture and surface. The rocks above, following syenitic gneiss and some of the schists, contain no quartz.

There is another related series, in which the rock contains hypersthene or diallage instead of hornblende, and quartz is mostly

or wholly wanting. It commences in the granite-like *hyperite*, consisting of crystallized feldspar (usually labradorite) and hypersthene. It passes into the tough and compact euphotide.

The hornblendic series blends laterally with the magnesian series, especially through the chloritic rocks of the latter, chlorite being near hornblende and pyroxene in composition, though containing water. It also blends with the mica series through granites and schists that contain both hornblende and mica. Through the pyroxenic varieties it also passes into the igneous series.

(1.) SYENITE.—Resembles granite, but contains in place of mica the mineral *hornblende*, which is in cleavable grains and either black or greenish black in color. The feldspar may be orthoclase or oligoclase, and sometimes the quartz is nearly wanting.

(2.) HYPERITE.—Granite-like in texture, and of rather dark color, consisting of cleavable *labradorite* (§ 55, *d*, usually dark and dull in color, either grayish, reddish, or brownish, with bright-colored internal reflections) and *hypersthene* (a lamellar cleavable variety of pyroxene, § 65 [14]). A common rock in the Azoic of northern New York and Canada.

(3.) DIORITE, or GREENSTONE.—Resembles syenite in appearance and granular crystalline texture, but contains little or no quartz: it consists of hornblende and albite or oligoclase (a triclinic feldspar). The rock is therefore whitish, speckled with black or greenish black. It is very tough. Sp. gr. 2.7–2.9. Graduates into a compact cryptocrystalline rock of a whitish, grayish, or greenish color.

Porphyritic diorite has the feldspar in distinct imbedded crystals. *Dioritic schist* is a diorite rock containing some mica and having a schistose structure.

(4.) HORNBLENDIC GNEISS.—Resembles gneiss in schistose structure, but contains hornblende in place of mica. *Zircon-syenite* is a syenite or hornblendic gneiss containing zircon with its other constituents.

(5.) HORNBLENDIC SCHIST.—A schistose rock consisting mainly of greenish-black hornblende with some feldspar; another variety, of hornblende and quartz; another is nearly pure hornblende; another contains epidote, and is therefore an *epidotic hornblendic schist*.

(6.) HORNBLENDE ROCK.—A very tough, granular, crystalline rock, consisting of hornblende, and hardly schistose in structure. Color, greenish-black to black.

(7.) ACTINOLITE ROCK.—A tough rock made of interlacing fibres of actinolite. Color, grayish green. A variety from St. François, Canada, afforded T. S. Hunt (Logan's Report for 1853–56, p. 445)—Silica, 52.30, magnesia, 21.50, protoxyd of iron, 6.75, lime, 15.00, alumina, 1.30, oxyd of nickel, a trace, water, 3.10 = 99.95.

(8.) PYROXENITE (*Cherzolite, Augite Rock*).—Coarse or fine granular pyroxene rock, consisting of granular pyroxene of a green, grayish green, to brown color, often streaked or clouded with darker or lighter shades of color. Often contains, or is associated with, quartz, talc, steatite, and calcite.

(9.) Diabase.—A massive hornblende rock, for the most part fine-grained in texture, having a grayish-green to greenish-black color. It is like diorite in composition, except that the feldspar is less abundant and is either labradorite or oligoclase.

(10.) Aphanite.—Aphanite consists mainly of hornblende, with some feldspar, and differs from the above in having a very compact or even a flinty appearance. Color, grayish green, greenish white, or gray. It has been called horn-rock.

Aphanite is sometimes slaty in structure, making an *aphanitic slate*. This rock in the hornblendic series corresponds to argillite in the mica-bearing series. It is distinguished from argillite by its greater specific gravity.

3. *Feldspathic, Epidotic, and Garnet Rocks having the mass or base compact (cryptocrystalline).*

85. These feldspathic rocks may be simply feldspathic, or the base may be partly hornblendic or quartzose. When they contain hornblende, garnet, or epidote, it is apparent in the higher specific gravity. (1.) Some of the light-colored rocks included are translucent and very tough, and contain grass-green diallage (called also smaragdite) in laminæ; these are called *euphotides*: they consist of feldspar, hornblende, epidote, or garnet. (2.) Others are opaque and often dark-colored, and usually contain crystals of feldspar disseminated through the mass; these are *porphyries*, or *porphyroid rocks*: they consist mainly of feldspar. (3.) The rocks consisting of the base of the euphotides without the diallage are called *petrosilex*.

a. Porphyroid Rocks.

(1.) Porphyrine.—Opaque, or nearly so. Colors, white, brown, red. In lustre and fracture much resembling jasper, from which it differs in being fusible before the blowpipe. Consists of feldspar: sometimes quartzose.

(2.) Feldspar-Porphyry.—Same as the last, with disseminated crystals of feldspar.

A *quartzose* variety of feldspar-porphyry has the base consisting of feldspar with some quartz. A variety of this kind occurs in eastern Massachusetts near Lynn. Crystals of quartz as well as feldspar are distributed through the mass. Colors, brownish-red and purplish. Specific gravity, 2.606.

(3.) Hornblendic Porphyry (Diabase Porphyry).—The antique green porphyry of Greece (southern Morea) is here included. Specific gravity, 2.91–2.932. Color, dark green; disseminated feldspar crystals, large, greenish white. Composition of the base: Silica, 53.55, alumina, 19.43, protoxyd of iron, 7.55, protoxyd of manganese, 0.85, lime, 8.02, magnesia and alkali, 7.93, water, 2.67. The iron and magnesia indicate the presence of hornblende or pyroxene.

Porcelanite, or *Porcelain-Jasper*.—A baked clay, having the fracture of flint and a gray to red color: it is somewhat fusible before the blowpipe, and thus differs from jasper. Formed by the baking of clay-beds through the heat from intrusive igneous dikes. Such clay-beds are sometimes baked to a distance of thirty or forty rods from the dike.

b. Petrosilex.

(1.) ORTHOCLASE-PETROSILEX.—Color, whitish, greenish; lustre somewhat waxy, dull; specific gravity, 2.6–2.7. A greenish-gray specimen from Brittany afforded Berthier—Silica, 75.4, alumina, 15.5, potash, 3.8, magnesia, 1.4, oxyd of iron, 1.2,—whence it consists of orthoclase, feldspar, and some quartz.

(2.) ALBITE-PETROSILEX.—Similar to the preceding. A variety from Orford, Canada, afforded T. S. Hunt (Logan's Report for 1853–56)—Silica, 78.55, alumina, 11.81, soda, 4.42, potash, 1.93, lime, 0.84, magnesia, 0.77, protoxyd of iron, 0.72, loss by ignition, 0.90 = 99.94. This rock graduates into feldspar-euphotide.

(3.) DIORITE-PETROSILEX.—Compact diorite, and consisting, therefore, of albite and hornblende. Color, grayish white, greenish white. Occurs in Orford, Canada (T. S. Hunt, Logan's Report, 1853–56).

(4.) GARNET-PETROSILEX.—A pure, compact, garnet rock, of a whitish color, with spots of disseminated serpentine. Specific gravity, 3.3–3.5. Composition of the base of this rock, from Orford, Canada, according to T. S. Hunt—Silica, 38.60, alumina, 22.71, lime, 34.83, magnesia, 0.49, oxyd of iron and manganese, 1.60, soda (with a trace of potash), 0.47, loss by ignition, 1.10 = 99.80. Specific gravity, 3.522–3.536. It is exceedingly hard and tough. Graduates into garnet-euphotide. A similar rock occurs at St. François, Canada.

c. Euphotides.

(1.) FELDSPAR-EUPHOTIDE.—Tough compact, light-green or grayish, consisting of a minutely-granular feldspathic base with disseminated diallage or smaragdite.

(2.) EPIDOTE-EUPHOTIDE.—Similar to the preceding, but more tough, and heavy. Specific gravity, 3.1–3.4. The base a compact whitish epidote (called hitherto saussureite), according to T. S. Hunt. From the Alps.

(3.) ECLOGITE, or GARNET-EUPHOTIDE.—Either whitish, greenish, or reddish; very tough and heavy. Specific gravity, 3.2–3.5. The eclogite of Europe contains grass-green smaragdite in a reddish garnet base. The related rock from Canada, according to T. S. Hunt (Logan's Report for 1853–56, p. 450), contains grayish cleavable hornblende or pyroxene in a whitish or yellowish base. Part of the base is in some cases feldspathic: its low specific gravity—2.8—serves to distinguish this variety.

4. *Hydrous Magnesian Series.*

86. The hydrous magnesian series, characterized by the presence of the hydrous magnesian minerals *talc*, *serpentine*, or *chlorite* (§ 66), ranges from a granite-like rock called *protogine* (containing the constituents of granite, excepting talc in place of mica) down to the semicrystalline talcose and chloritic slates: and also to compact flinty rocks near aphanite. Besides these, there are the serpentine rocks. Talc and serpentine are silicates of magnesia and water alone, while chlorite contains alumina and oxyd of iron. The chloritic rocks consequently abound often in hornblende, and are frequently associated with rocks of the hornblende series. The

color of the rocks is some shade of dull grayish, brownish, olive, or blackish green. Specific gravity, 2.4 to 3; or over 3 if containing hornblende.

(1.) Protogine.—A granular crystalline or granite-like rock, consisting of quartz, feldspar, and talc, with sometimes some mica (micaceous protogine). The feldspar may be orthoclase or oligoclase, or both (both in the Alps), and is sometimes in distinct crystals (porphyry). Color, grayish white or greenish white. Gneissoid protogine is a gneiss-like rock, consisting of quartz, feldspar, and talc, between talcose schist and gneiss in its characters. Occurs in the Alps.

(2.) Chloritic Gneiss.—A gneissoid rock consisting of quartz and feldspar, and often mica, with soft olive-green granular chlorite distributed through it in small patches.

(3.) Talcose Schist.—A slaty rock, less crystalline than mica schist, and less evenly schistose, characterized by a slight greasy feel, glistening and talcose look upon the surface of the slate, a greenish-gray or grayish-green to brown color. Texture usually near that of argillite, sometimes with quartz and feldspar in grains like mica schist. It passes on one side into *schistose talc*, which is very greasy to the feel, and is pure talc; and on the other into argillite, or mica schist. Frequently contains actinolite, garnet, staurotide, tourmaline, pyrites; and the intersecting or intercalated quartz often contains gold.

(4.) Steatite, or Soapstone (§ 66).—A massive, more or less schistose rock, fine-granular; color, gray to grayish-green; feel, very soapy; composition, that of fine talc. Often contains crystals of tourmaline (p. 58), dolomite, or brown spar (p. 63), or magnetite (p. 65).

Rensselaerite is a kind of soapstone, of compact texture, and either gray, whitish, greenish, brownish, or even black, color. For an analysis by T. S. Hunt, see Logan's Rep. for 1853–56, p. 483. Occurs in the towns of Fowler, De Kalb, Gouverneur, and others, St. Lawrence co., N.Y., and also in Grenville, Canada.

(5.) Chloritic Schist.—A more or less slaty rock, like the preceding, but of an olive-green or greenish-black color, though sometimes pale greenish-gray; it is somewhat less greasy to the feel, usually less shining; the chlorite fine-granular and soft; sometimes in deep-green mica-like scales or plates. Often contains black and dark-green hornblende in acicular and grouped crystals and fibrous masses, also magnetite in octahedral crystals. Graduates into hornblendic slate. A rock of this kind from Potton, Canada, analyzed

by T. S. Hunt, has the composition of ordinary chlorite. (Logan's Rep. for 1853–56.)

(6.) SERPENTINE (§ 66).—A massive uncleavable rock, of dark-green to greenish-black color, easily scratched with a knife, and often a little greasy to the feel when a surface is smoothed. Although generally of a dark-green color, it is sometimes pale grayish and yellowish green, and mottled.

A serpentine rock containing diallage is the *gabbro* of the Italians.

(7.) SCHILLERITE, or Schiller rock, Diallage rock.—A dark-green to greenish-black rock, made up of Schiller spar, and having the following composition: 1, Köhler; 2, T. S. Hunt (Logan's Rep., 1855–56, 443); 3, id. of the pure diallage :—

	SiO^3.	Al^2O^3.	FeO.	MgO.	CaO.	NiO.	MnO.	HO.	
1.	43.90	1.28	13.01*	26.86	......	......	0.54	12.43	Köhler.
2. Canada......	41.80	6.80	11.05	26.13	7.00	trace	......	7.60	Hunt.
3. Canada......	47.15	3.45	8.73	24.56	11.35	trace	......	5.82	Hunt.

It is often associated with serpentine, chlorite, and talc-schist.

(8.) OPHIOLITE (or verd-antique marble).—A variegated mixture of serpentine and either carbonate of lime (*calcareous ophiolite*), dolomite (*dolomitic ophiolite*), or carbonate of magnesia or magnesite (*magnesitic ophiolite*). Color, dark green, mottled with lighter green or white.

It often contains chromic iron sparsely disseminated through it, forming irregular, black, submetallic spots; also some talc, asbestus, sahlite; and analysis often detects nickel as well as chrome. T. S. Hunt has found both nickel and chrome in the serpentines or ophiolites of the Green Mountain range, in those of Roxbury, Vt.,.New Haven, Ct., Hoboken, N.J., Cornwall, England, Banffshire, Scotland, Vosges, France. They occur also in the pyrosclerite and Williamsite of Chester co., Pa., and in the antigorite of Piedmont. Hunt found no nickel in serpentine from Easton, Pa., Montville, N.J., Philipstown, N.Y., Modum, Norway, Newburyport, Mass., and none from the Azoic series of rocks.

5. *Hydrous Aluminous rocks.*

87. These rocks consist largely of agalmatolite or pyrophyllite, and have a close resemblance to talcose and serpentine rocks in feel, hardness, and appearance.

PAROPHITE.—Essentially agalmatolite (§ 67) in composition. Its fine-grained texture and somewhat soapy feel are its striking peculiarities. It occurs both as a slate and rock. The name was first given by T. S. Hunt to a variety occurring in northern Vermont, and alludes to a resemblance in aspect to serpentine. The dysyntribite of Shepard, found in northern New York (§ 67), is a rock variety.

* With some oxyd of chrome.

PYROPHYLLITE ROCK *or* SCHIST.—Like the preceding in appearance and soapy feel, but having the composition of pyrophyllite (§ 67). The color is white and gray, or greenish white. Occurs in North Carolina; one of the varieties from the Deep River region is used for slate-pencils.

6. *Quartzose rocks.*

88. (1.) QUARTZITE, or Granular Quartz Rock.—A very hard, compact rock, consisting of quartz grains or sand, and usually either white, gray, or grayish red in color. Sometimes contains disseminated scales of feldspar, mica, or talc, and in that case is often laminated or schistose. It is but a step removed from ordinary sandstone, and owes its peculiarities only to a process of consolidation.

(2.) SILICEOUS SCHIST.—A schistose, flinty quartz rock, not distinctly granular in texture.

(3.) ARKOSE.—A quartz rock, containing much crystallized orthoclase disseminated through it. Occurs in the Vosges.

(4.) ITACOLUMITE.—A schistose quartz rock, consisting of quartz grains with talc or mica. On account of the talc or mica in the lamination, the finer kind is sometimes flexible, and is called *flexible sandstone*. Occurs often in gold-regions associated with talcose slates.

(5.) JASPER ROCK.—A flinty siliceous rock, of dull red, yellow, or green color, or some other dark shade, breaking with a smooth surface like flint. It consists of quartz, with more or less clay and oxyd of iron. The red contains the oxyd of iron in an anhydrous state, the yellow in a hydrous: on burning the latter it turns red.

A dull-green *chert* (or impure flinty siliceous rock) from Cap Rouge, Canada, afforded T. S. Hunt (Logan's Report for 1853–56)—Silica, 77.50, alumina, 8.50, protoxyd of iron, 2.70, lime, 0.73, magnesia, 2.35, soda, 1.38, potash, 1.66, loss by ignition, 4.40 = 99.22. Part of the silica—nearly 21 per cent.—was in the condition of opal.

(6.) BUHRSTONE.—A cellular siliceous rock, flinty in texture. It is used for millstones. Found mostly in connection with Tertiary rocks, and formed apparently from the action of siliceous solutions on pre-existing fossiliferous beds.

7. *Iron-Ore rocks.*

89. SPECULAR IRON-ORE (*Hematite*) and MAGNETIC IRON-ORE occur as rocks of considerable thickness among the metamorphic rocks, especially the hornblendic and chloritic kinds. There are schistose or laminated as well as massive varieties. These iron-ore beds occur extensively in northern New York, Canada, Michigan, and Missouri; also in Sweden and elsewhere. Their alternation with chloritic and other schists and gneissoid rocks shows that they are meta-

morphic as well as the schists. *Titanic iron-ore* occurs in great beds of like extent in Canada. (See § 72.)

Franklinite, an iron-zinc ore, is also one of the metamorphic rocks in northern New Jersey.

3. Calcareous Rocks.—Carbonates and Sulphates.

90. (1.) Massive Limestone.—*Uncrystalline Limestone.*—Most limestone has been formed from shells and corals ground up by the action of the sea and afterwards consolidated. The colors are dull gray, bluish, brownish, to black. The composition is usually the same as that of calcite, *carbonate of lime* (§ 69), except that impurities, as clay or sand, are often present. In texture they vary from an earthy-looking limestone to a very compact semi-crystalline one; and from this kind the passage is gradual also to the true crystalline.

(2.) Magnesian *or* Dolomitic Limestone (§ 69 [24]).—Consists of carbonate of lime and magnesia, but is not distinguishable in color or texture from ordinary limestone. The amount of carbonate of magnesia present varies from a few per cent. to that in dolomite. Much of the common limestone of the United States is magnesian.

Analyses of magnesian limestones:—1. Lower magnesian (Calciferous epoch), by D. D. Owen; 2, id. of Iowa, J. D. Whitney; 3, Galena limestone of Iowa, Whitney; 4, Niagara limestone, by Beck; 5, Carboniferous limestone of Iowa, Whitney.

	1. St. Croix.	2. New Galena.	3. Garnaville.	4. Lockport.	5. Mt. Pleasant.
Carbonate of lime	48.24	52.47	52.01	75.65	57.15
Carbonate of magnesia	42.43	42.13	42.25	20.70	39.24
Carbonate of iron	......	1.78	0.93	......	......
Insoluble (sand)	2.74	2.75	4.43	2.25	2.18
Oxyd of iron and alumina	6.14	0.87*	0.38	Ox. iron 0.35	1.06
Moisture	0.40	....	....	and loss 1.05	0.31†
	99.95	100.00	100.00	100.00	99.94

In some limestones the fossils are magnesian limestone, while the rock is common limestone. Thus, an Orthoceras in the Trenton limestone of Bytown, Canada (which is not magnesian), afforded T. S. Hunt—Carbonate of lime, 56.00, carbonate of magnesia, 37.80, carbonate of iron, 5.95 = 99.75. The pale-yellow veins in the Italian black marble called "Egyptian marble" are dolomite, according to T. S. Hunt, and a limestone at Dudswell, Canada, is similar.

(3.) Hydraulic Limestone.—An impure or earthy limestone, con-

* Alkalies and loss. † Carbonate of soda and trace of potash.

taining some clay, and affording a quicklime the cement made of which will set under water. An analysis of a kind worked at Rondout, N.Y., afforded Beck—Carbonic acid, 34.20, lime, 25.50, magnesia, 12.35, silica, 15.37, alumina, 9.13, sesquioxyd of iron, 2.25.

(4.) Oolite, or Oolitic Limestone.—A rock consisting of minute concretionary spherules, and looking like the petrified roe of fish: the name is from the Greek *ωον*, egg. It is sometimes magnesian.

(5.) Chalk.—A white, earthy limestone, easily leaving a trace on a board. Composition, the same as that of ordinary limestone.

(6.) Marl.—A clay containing a large proportion of carbonate of lime,—sometimes 40 to 50 per cent. If the marl consists largely of shells or fragments of shells, it is called *shell-marl.*

(7.) Shell Limestone.—*Coral limestone.*—A rock consisting of shells or corals.

(8.) Birdseye Limestone.—A compact limestone having crystalline points disseminated through it.

(9.) Travertine.—A massive but porous limestone, formed by deposition from springs or streams holding carbonate of lime in solution in the state of bicarbonate. The rock abounds on the river Anio, near Tivoli, and it is there used as a building-material. St. Peter's, at Rome, is constructed of it. The name is a corruption of *Tiburtine.*

(10.) Stalagmite, Stalactite.—Depositions from waters trickling through the roofs of limestone caverns, form pendent calcareous cones and cylinders from the roofs, which are called *stalactite,* and incrustations on the floors, which are called *stalagmite.* The layers of successive deposition are usually distinct, and make the material appear banded. They are rarely transparent, usually translucent to subtranslucent or opaque, and white, grayish, or faint yellowish in color.

2. *Crystalline Limestone.*

91. Granular Limestone (§ 69) (Statuary Marble).—Limestone having a crystalline granular texture, white to gray color, often clouded with other colors from impurities. The impurities are often *mica* or *talc, tremolite, white* or *gray pyroxene,* or *scapolite;* sometimes *serpentine,* through combination with which it passes into ophiolite (§ 86), chondrodite, apatite, corundum.

Dolomite.—Not distinguishable by the eye from granular limestone (§ 69).

3. *Consisting of Sulphate of Lime.*

92. Gypsum.—Sulphate of lime, as described in § 70. The earthy kinds often contain the crystallized mineral in spots or fissures; and in many places it is associated with anhydrite, or sulphate of lime containing no water (§ 70 [27]). The borate of magnesia,

(*Boracite*), and Polyhalite, are often found in gypsum-beds; also, rarely, hydrous borate of lime (*Hayesine*), as in Nova Scotia.

Gypsum is deposited from sea-water; but the gypseous rocks appear generally to have been formed by the action of sulphuric acid (from decomposition of sulphurets or volcanic vapors) on limestone or *carbonate* of lime. The action drives off the *carbonic acid* and makes *sulphate* of lime, or *gypsum*.

4. Igneous Rocks.

93. Igneous rocks are those which have been ejected in a melted state either from volcanoes or through fissures in the earth's crust. As the crystallizing of superficial deposits may produce rocks like those that are of true igneous origin, the same species in a few cases occur in both divisions. Thus, there are metamorphic diorite and porphyry, as well as igneous diorite and porphyry. The igneous rocks differ from most of the metamorphic series in the absence or very sparing occurrence of quartz.

There are two series of igneous rocks,—the *feldspathic*, having light colors and being of low specific gravity, and the *augitic*, having dark colors with high specific gravity.

1. *Feldspathic series.*—Consisting mainly of a feldspathic base, with, often, disseminated crystals of some kind of feldspar, or of hornblende or pyroxene. Color, white, gray, bluish gray, grayish brown. G. = 2.4–2.8. Occasionally, as in the porphyries, dark red and brown. The light colors and low specific gravity are owing to the absence or sparing dissemination of iron.

2. *Augitic series.*—Consisting of feldspar and hornblende or augite (greenish-black or black pyroxene). Color, dark gray, dark grayish brown, dark greenish brown, greenish-black to black. G. = 2.9 –3.6. The high specific gravity and dark colors are owing to the presence of iron as magnetic or titanic iron, or as a constituent of the augite or hornblende.

1. *Feldspathic Series.*

94. (1.) Feldspathic Trap.—A rock consisting of crystallized feldspar, and sometimes called, from its color, *white* trap. Varieties occurring in Canada have a whitish, grayish, or pale yellowish color, also a pale fawn color. Composition of a variety from Chambly, Canada, according to T. S. Hunt (Logan's Rep. for 1853–56), consisting of *orthoclase*, as follows:—

	SiO^3.	Al^2O^3.	Fe^2O^3.	CaO.	NaO.	KO.	Ignition.	
1. Crystals.	66.15	19.75	——	0.95	5.19	7.53	0.55 =	100.12
2. Paste.....	67.60	18.30	1.40	0.45	5.85	5.10	0.25 =	98.95

Certain dikes in the Montreal Mountain are of this kind, except that in some the feldspar is a soda feldspar. Found also at Lachine. A similar rock occurs in Australia in Prospect Hill, near Paramatta, New South Wales.

(2.) PORPHYRY.—A rock the mass or base of which is a compact uncleavable feldspar, containing disseminated crystals of feldspar (orthoclase or oligoclase), giving it an appearance, when polished, of being spotted with white or some pale color, the spots rectangular or nearly so in form. Color, base grayish, purplish, to deep red and brown; and crystals either large or minute. The feldspar either orthoclase or oligoclase; mica or hornblende sometimes present. Specific gravity of the red antique porphyry, 2.62–2.77.

This rock closely resembles true metamorphic porphyry, like that from the vicinity of Boston. The antique green porphyry of Greece is diabase porphyry (§ 85). G. = over 2.9.

Much of the so-called porphyry of the Andes and Mexico is a porphyry conglomerate, in which both the pebbles and base are spotted with feldspar crystals, and the texture looks homogeneous until closely examined.

(3.) PHONOLITE (Clinkstone).—Compact, of grayish blue and other shades of color, more or less schistose or slaty in structure; tough, and clinking under the hammer like metal when struck, whence the name. Often contains disseminated crystals of glassy feldspar and hornblende, and sometimes mica. Consists of glassy feldspar (orthoclase or oligoclase), with nepheline or a zeolite (§ 68). Action of muriatic acid separates it into a soluble and an insoluble state, the former including all the nepheline or zeolite. Analysis by Jenzsch of the Bohemian phonolite,—Silica, 56.28, alumina, 20.58, lime, 0.46, soda, 9.07, potash, 5.84, lithia, 0.05, protoxyd of iron, 2.86, protoxyd of manganese, 1.45, magnesia, 0.32, titanic acid, 1.44, phosphoric acid, 0.29, loss by ignition, 1.29, chlorine, 0.54, sulphur, 0.02; from which he deduces that it consists of 53.55 of glassy feldspar, 31.76 of nepheline, with some hornblende and sphene (nepheline or zeolite). Other phonolites consist of 18 to 50 per cent. of soluble silicate.

Common Phonolite.—Schistose, without distinct feldspar crystals, and containing a zeolite disseminated through the mass, which is usually regarded as an essential ingredient of the rock.

A peculiar feldspathic igneous rock occurring at Lachine, in Canada, having a reddish, fawn-colored base, brittle, G. = 2.414, and H. = 5, consists, like phonolite, of feldspar (orthoclase) and a zeolite (probably natrolite) in nearly equal parts. It forms dikes, and is in the same region with the dikes of *white trap* mentioned in § 94 (1).

Porphyritic Phonolite.—Containing disseminated glassy feldspar crystals.

Phonolitic Lava.—Differing from trachyte in being more cellular and in not having the peculiar roughness of trachyte over a surface of fracture.

(4.) TRACHYTE.—Color, pale grayish blue, rarely greenish, yellowish, reddish; texture peculiarly rough to the feel, and usually porous. Often contains disseminated crystals of glassy feldspar and hornblende, and some little free quartz, also mica. G. = 2.6–2.7. Decomposed by the action of muriatic acid into a soluble and an insoluble silicate, the former in less proportion than in clinkstone, or 10 to 14 per cent. Composition of the whole (from Drachenfels), according to Abich,—Silica, 67.09, alumina, 15.64, potash, 3.47, soda, 5.08, lime, 2.25, oxyds of iron, 4.59, magnesia, 0.98, protoxyd of manganese, 0.15,

titanic acid, 0.38, water, etc., 0.45. In others, silica forms 61 to 67 per cent. of the whole.

Trachytic lava.—A very cellular trachyte.

Domite.—An earthy friable trachyte, from Puy de Dome, Auvergne.

Slaty trachyte.—Structure schistose.

Porphyritic trachyte.—Containing disseminated crystals of glassy feldspar, often without any hornblende.

Granitoid trachyte.—A granular aggregate of glassy feldspar, hornblende, and mica. Approaches *diorite.*

Hornblendic trachyte.—Containing much hornblende in disseminated crystals.

(5.) PUMICE.—Very light, porous, with the pores minute, capillary, and parallel. Color, pale grayish, greenish, yellowish, and sometimes of darker shades. It is a kind of porous trachyte. Contains 69 to 70 per cent. of silica, and probably, therefore, some free quartz. Composition, according to Berthier,—Silica, 70.0, alumina, 16.0, sesquioxyd of iron, 0.5, lime, 2.5, potash, 6.5, water, 3.00 = 98.50. Abich obtained 6.21 per cent. of soda, and 3.98 of potash.

Often contains glassy feldspar, and sometimes hornblende, mica, leucite.

(6.) OBSIDIAN.—A volcanic glass, taking its characters from the composition of the volcanic lavas. The lavas cooling slowly form stony lava, and cooling rapidly a glassy,—the two being different conditions of the same substance.

Obsidian connected with feldspathic lavas is either solid or slag-like (scoriaceous), and in color brown to greenish-black and black. A Mexican variety afforded Vauquelin—Silica, 78, alumina, 10, potash and soda, 6, lime, 1, sesquioxyd of iron, 2, id. of manganese, 1.6 = 98.6. Another, from Telki-Banya, afforded Erdmann—Silica, 74.80, alumina, 12.40, potash and soda, 6.40, lime, 1.96, sesquioxyd of iron, 2.03, id. of manganese, 1.31, magnesia, 0.90 = 99.80.

Spherulitic obsidian.—Contains small feldspathic concretions.

(7.) PITCHSTONE (Retinite).—An imperfectly-glassy volcanic rock, pitch-like in appearance, and of various colors from gray to black, through greenish, reddish, and brownish shades. It contains 70 to 73 per cent. of silica, and, in some of the published analyses, 8 to 10 per cent. of water. Delesse obtained (Bull Soc. Geol. de France, 1853, p. 105) for a pitchstone from Santa Natolia—Silica, 62.59, alumina, 16.59, protoxyd of iron, 3.17, id. of manganese, 0.55, lime, 1.15, magnesia, 2.26, potash, 6.48, soda, 3.14, water and organic matter, 3.90 = 99.83.

(8.) PEARLSTONE.—Near pitchstone, but less glassy and more pearly in lustre: usually grayish in color, also yellowish, brownish, and reddish. The peculiar pearly appearance is due to an intimate mixture of a portion of the rock in the glassy state with another larger portion in the stony state. It often contains spherical concretions, called *spherulites*, which consist of feldspar with an excess of quartz. The silica varies from 68 to 80 per cent. An analysis by Erdmann of a variety from Hlinick afforded—Silica, 72.87, alumina, 12.05, soda and potash, 6.13, lime, 1.30, magnesia, 1.10, sesquioxyd of iron, 1.75, water, 3.00 = 98.20.

(9.) MELAPHYR.—Closely related in its connections to dolerite and basalt, but consisting of compact labradorite, and having a specific gravity not above 2.7. Color, reddish gray, greenish blackish, and sometimes mottled. Different rocks

have been included under this name. Some that have been called trap are here included.

2. *Augitic or Basaltic Series.*

95. (1.) DIORITE.—Similar to the metamorphic diorite, but usually the hornblende less abundant and the feldspar less finely developed. Color, grayish white. A variety consisting of hornblende and anorthite constitutes some of the dikes of Canada. (T. S. Hunt.)

(2.) DOLERITE (*Trap*, in part).—Texture crystalline-granular to cryptocrystalline (the fine variety often called *anamesite*). Color, dark gray, greenish and brownish black. Consists of labradorite and augite, with often magnetic iron. Sometimes columnar. G. = 2.75–3.

Porphyritic dolerite.—Speckled with crystals of feldspar, or with feldspar and augite, or with augite alone.

Amygdaloidal dolerite.—Containing nodules of zeolites, chlorite, quartz, or calcite. Includes much of the so-called *amygdaloid.*

Another variety contains the augite in black crystals.

Doleritic lava.—Structure scoriaceous or very cellular.

(3.) BASALT.—Like dolerite, but less granular than the coarser dolerite, and containing also chrysolite in grains looking like green glass. Compact. Often columnar. G. = 2.9–3.2.

Porphyritic basalt.—Speckled with crystals of feldspar.

Amygdaloidal basalt.—Containing amygdals of zeolites, etc. (§ 68).

Basaltic lava.—Scoriaceous or very cellular. The lava may be porphyritic with feldspar or augite crystals.

(4.) LEUCITOPHYR.—A dark-grayish, fine-grained, cellular volcanic rock, consisting of augite and leucite with some disseminated magnetic iron. It is the lava of Vesuvius. The leucite is either in whitish grains or in trapezohedral crystals (see § 57), and is disseminated like the feldspar crystals in a porphyry.

(5.) NEPHELINITE (*Nephelin-dolerite*).—A crystalline, granular volcanic rock, consisting of nepheline and augite, with some magnetic iron, the nepheline partly in distinct crystals. Color of the coarser kind, grayish or whitish; of the finer, dull ash-gray.

The tufas and conglomerates of volcanic regions are noticed on p. 74.

Wacke is an earthy rock made of basaltic earth partially compacted,—a kind of tufa.

(6.) BASALTIC OBSIDIAN.—The massive obsidian of Kilauea, Hawaii, a region of basaltic lavas, contains 22 per cent. of protoxyd of iron, and the capillary (Pélé's hair) 30 per cent. The light scoria of the crater is an impure volcanic glass, very much inflated.

II. CONDITION, STRUCTURE, AND ARRANGEMENT OF ROCK-MASSES.

96. The rock-masses of the globe, or *terrains*, as they are called, occur under three CONDITIONS: (1) the *stratified*, (2) the *unstratified*, and (3) the *vein* condition. Under each there are different peculiarities of STRUCTURE and of ARRANGEMENT.

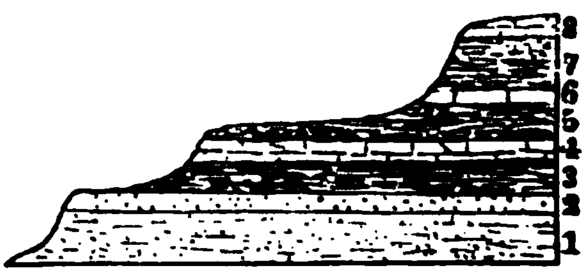
1. STRATIFIED CONDITION.

Under this head the subjects for consideration are:—1. The nature of stratification; 2. The structure of layers; 3. The positions of strata,—both their natural positions and dislocations; 4. The general arrangement of strata, or their chronological order.

1. *Nature of Stratification.*

97. Stratified rocks are those which are made up of a series of layers or strata. The annexed sketch represents a section of the strata as exhibited along Genesee River, at the falls near Rochester. The whole height of the section is 400 feet. At bottom there is a thick stratum of sandstone (1); next above it lies a hard, gray layer (2), which has been called the *Gray Band.* Upon this rests (3) a thick bed of greenish shale, a fragile, imperfectly slaty rock. Next (4) is a compact limestone forming a widespread stratum resting on the shale. Above this (5) is another greenish shale, much like that below. Then (6) is another great stratum of limestone; then (7) another thick bed of shale; and, finally (8), at the top is a limestone wholly different from those below. The transition from one stratum to another is quite abrupt, and, moreover, each may be traced for a great distance through the adjoining country.

Fig. 60.



Throughout far the larger part of America and all the other continents the rocks lie similarly in layers, so that stratified rocks are of almost universal distribution. They make up the most of the Appalachians; cover nearly all of New York; underlie the great plains of the Ohio and Mississippi; occur over the larger part of the slopes and summit of the Rocky Mountains, along much of the Pacific border, as well as the Atlantic; and exist as red sandstone

in the Connecticut valley. They are the prevailing rocks of Britain, including within their series the chalk, oolite, coal strata, and others. They occur over nearly all Europe, spread throughout the great plains of Russia, through Asia nearly to the top of the Himalayas, South America in many places to the summit of the Andes, and through Africa and Australia. These stratified rocks are in striking contrast with the unstratified,—granite, for example, which may show no appearance of layers even through heights of a thousand feet or more. Many volcanic masses of rock are unstratified. Yet the volcanic mountain has usually a *stratified* arrangement, successive layers of lava and volcanic sand or earth being piled up to make the cone. Even among crystalline rocks the distinction of strata may often be made out, although much disguised by changes in the course of their history.

The succession of strata in stratified rocks is exceedingly various. In the section given, there are alternations of limestones, shales, and sandstone. In others, as at Trenton Falls, N.Y., there are only limestones in sight; but were the rocks in view to a much greater depth, sandstone strata would be seen. In still other regions, there are alternations of conglomerates and shales; or conglomerates with shales and coal-beds; or conglomerates with limestones and sandstones; or shales and sandstones alone.

The thickness of each stratum also varies much, being but a few feet in some cases, and hundreds of feet in others; and the same stratum may change in a few miles from 100 feet to 10, or disappear altogether. In the Coal formation of Nova Scotia there are 14,000 feet of stratified beds, consisting of a series of strata mainly of sandstones, shales, and conglomerates, with some beds of coal; and in the Coal formation of Pennsylvania there are 6000 to 7000 feet of similar character.

98. After these illustrations, the following definitions will be understood.

a. Stratification.—A succession of rock-layers, either of the same or of different kinds.

b. A *layer.*—A single member or bed in a stratified rock. It may be thick or thin, and loosely or strongly attached to the adjoining layers. In the section, fig. 60, the limestones 4 and 6 consist of a great number of layers; and in all limestone regions many are piled together to make the great mass of limestone.

c. A *stratum.*—The collection of layers of one kind which form a rock as it lies between beds of other kinds. In the section referred to (fig. 60), the limestones 4, 6, and the shale masses 3, 5, 7, are each a *stratum.* A stratum may consist of many *layers.*

d. A *formation*.—A series of strata comprising those that belong to a single geological *age* or a single *period*, or subdivision of an age, and which, consequently, have a general similarity in their fossils or organic remains. The *Coal formation* includes many *strata* of sandstone, shales, limestones, and conglomerates.

While this is always the general idea connected with the term *formation*, the use of it is not uniform. Geologists speak of the Silurian formation, Devonian formation, Carboniferous (or Coal) formation, etc., making each cover a geological *age*. But they often apply the term also to subordinate parts of these formations. Thus, under Silurian we have the *Upper Silurian formation* and the *Lower Silurian formation*; and under each of these there are subordinate formations, as the *Trenton formation*, including several strata of the Trenton period in the Lower Silurian; the *Niagara formation* for the lower part of the Upper Silurian. These subdivisions embrace generally many strata, and have striking peculiarities in their organic remains; and hence this use of the word *formation*.

e. A *seam* is a thin layer intercalated among the layers of a rock, and differing from them in composition. Thus, there are seams of coal, of quartz, of iron-ore. *Seams* become *beds*, or are so called, when they are of considerable thickness; as, for example, *coal-beds*.

99. These strata, which constitute so large an extent of the earth's crust, have been formed mainly by the action of water. As the ocean now makes accumulations of pebbles, sand, and muddy flats along its borders, and muddy bottoms for scores of miles in width along various sea-shores, so it formed by the same means many of the strata of sand and clay which now constitute the earth's rocks; and in this work the sea often had the advantage, in early times, of sweeping widely over the just-emerging continent. Again, as the rivers bring down sand and mud and spread them in vast alluvial flats, making deltas about their mouths thousands of square miles in area, so in ancient time beds of sand and clay were accumulated by these very means and afterwards consolidated into rocks. Again, as shells and corals, by growing in the ocean where shallow, under the action of the waves, produce the accumulating and rising coral-reef some hundreds of miles long in the present age, so in former ages shells and corals grew and multiplied and made coral-reefs and shell-rocks, and these old reefs are the limestone strata of the world. The agency of water and life in these great results is particularly considered under Dynamical Geology.

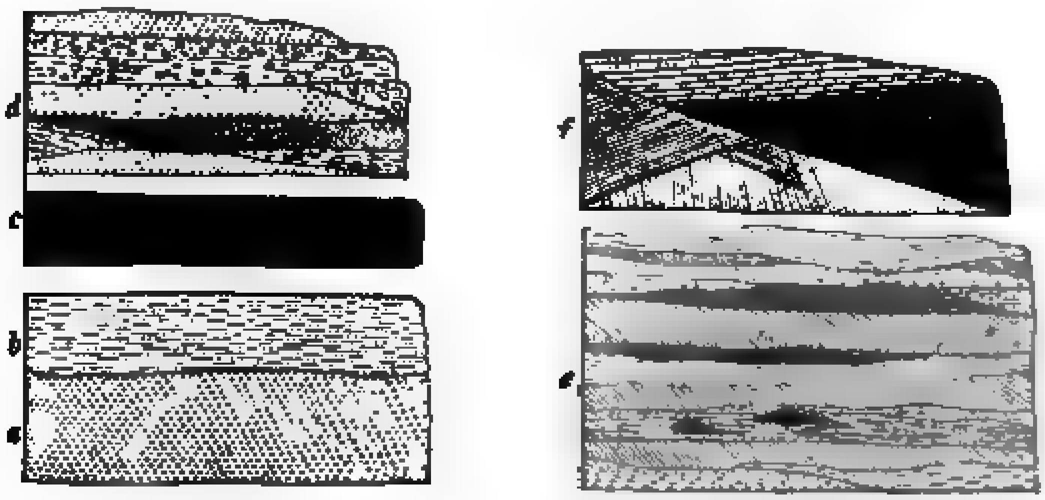
2. *Structure of Layers.*

The structure of layers is due either to the original deposition of the material, or to subsequent changes.

100. (1.) **Kinds of structure and markings originating in the**

act or mode of deposition.—The kinds of structure are illustrated in the annexed figure, and are as follow:—*a*, the *massive*; *b*, the *shaly*; *c*, the *laminated*; *d* and *e*, the *compound* or *irregularly bedded*.

Fig. 61.



These terms, excepting the last, have been already explained (§ 80). The *massive* is especially characteristic of pure sandstones and conglomerates. But if sandstones are argillaceous, that is, contain some clay, they are *laminated*, or break readily into slabs, like ordinary flagging-stones; and the thinness of the flags increases with the amount of clay. A clayey rock is usually *shaly* or an imperfect slate.

The *compound structure* is of three kinds,—the *beach structure*, the *ebb-and-flow structure*, and the *sand-drift structure*.

In the *beach structure*, as exemplified in *d*, the subordinate layers are very irregular in thickness and extent, often thinning out at short intervals and varying from pebbles or stones to sand and clay. This structure is observed in any sea-beach where a cut has exposed its interior arrangement.

In the *ebb-and-flow structure* (*e*), the bed, although it be but a few feet thick, consists of layers of various kinds, some of which are horizontally laminated, and others obliquely so with great regularity, as in the figure. The succession of members indicates frequent changes or reversals in the currents during the deposition. Such changes attend the ebb and flow of the tides or tidal currents or waves over a shallow bottom.

In the *sand-drift structure* (*f*), the layers consist of subordinate parts of very various lamination, one dipping in one direction and another in another, as if a laminated hillock made by sand drifted by the winds on a coast (for such sand-drifts are always in layers) had been partly carried away, and then other layers been thrown

over it by the drifting winds at a new inclination, and this violent removal and replacement often and variously repeated. Fig. 61 *f*, representing this mode of structure, is from Foster & Whitney's Report on the Sandstone Rocks of Lake Superior. Fig. 61 *e* is also from the same work.

101. Besides these kinds of structure, there are *markings* in the strata which are of related origin,—viz.: ripple-marks, wave-marks, rill-marks, mud-cracks, and rain-drop impressions.

Fig. 62.

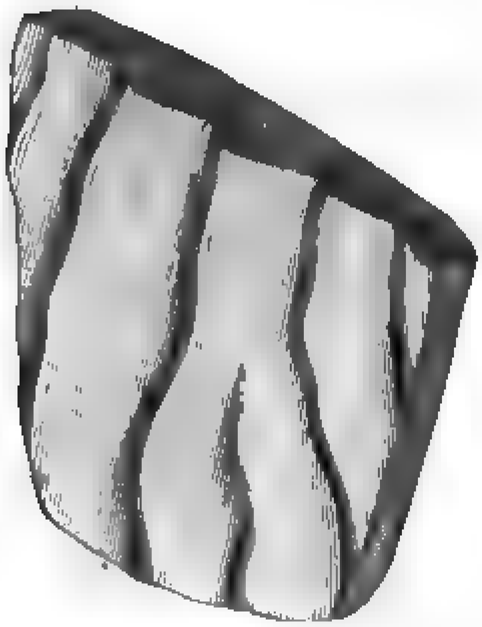
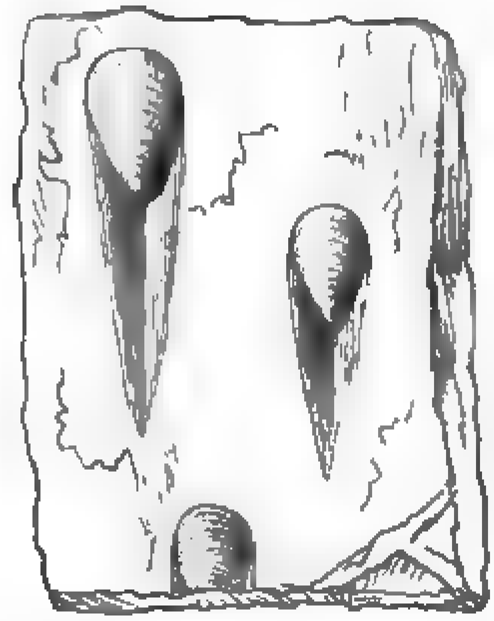


Fig. 63.



(1.) *Ripple-marks* (fig. 62).—A series of wavy ridgelets, like the ripples on a sand-beach.

(2.) *Wave-marks.*—Faint outlinings, of curved form, on a sandstone layer, like the outline left by a wave along the limit where it dies out upon a beach.

(3.) *Rill-marks* (fig. 63).—Little furrows made by the rills that flow down a beach after the retreating wave or tide, and which become apparent especially where a pebble or shell lies, the rising of the water upon the pebble causing a little plunge over it and a slight gullying of the surface for a short distance.

(4.) *Mud-cracks* (figs. 64 and 65).—Cracks intersecting very irregularly the surface or a portion of a layer, and formed by the drying of the material of the rock when it was in the state of mud, just as a mud-flat left exposed to the drying sun now cracks. The original cracks are usually filled with a material harder than the rock, so that when it becomes worn the surface has a honeycomb appearance, from the prominence of the intersecting ridgelets, as in fig. 65. Moreover, these ridges are generally double, the filling

having been solidified against either wall of the crack until the two sides met at the centre and became more or less perfectly

Fig. 64.

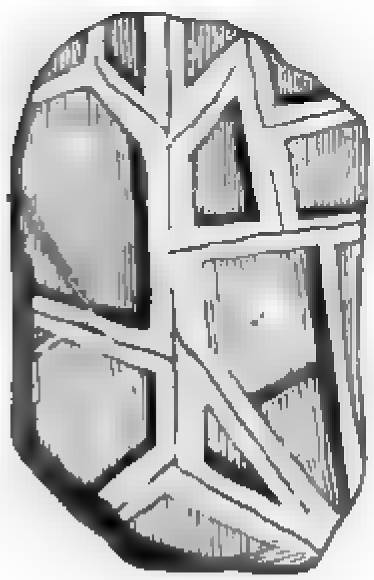
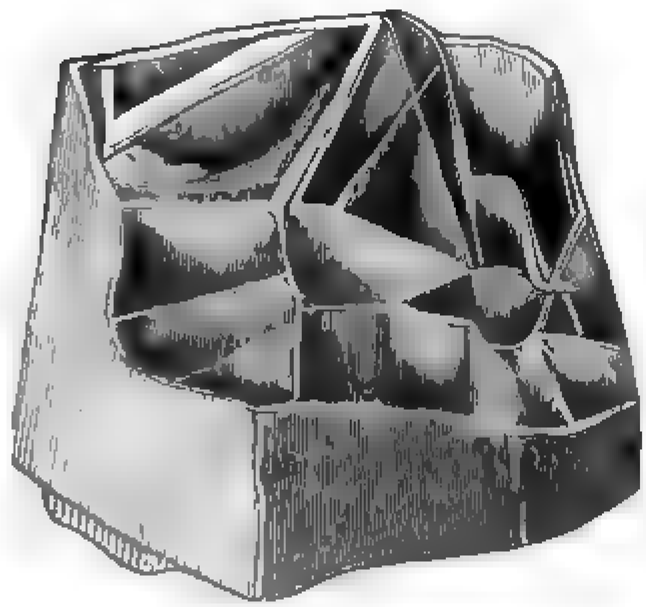
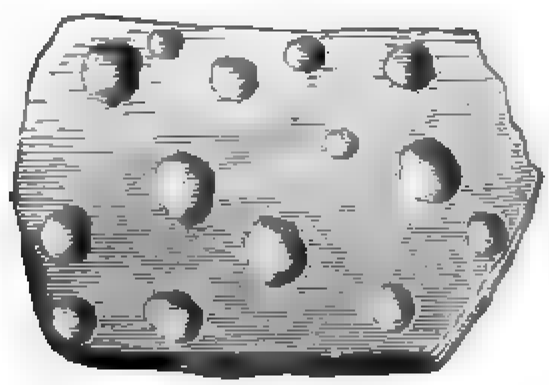


Fig. 65.



united. Specimens of rock thus honeycombed are sometimes called *septaria* (from *septum*, partition); but the term is little used in science.

Fig. 66.



(5.) *Rain-prints* (fig. 66).—Rounded pits or depressions, made by drops of rain on a surface of clay or half-dry mud. On a reversed layer the impressions appear raised instead of depressed, being casts made in the pits which the rain had formed.

(6.) There are also markings which are attributed to the *flowing of thick mud*. There are others, produced apparently by small eddyings of water in clay or mud which work out concavities that afterwards become filled with clay and look as if made by the valves of shells.

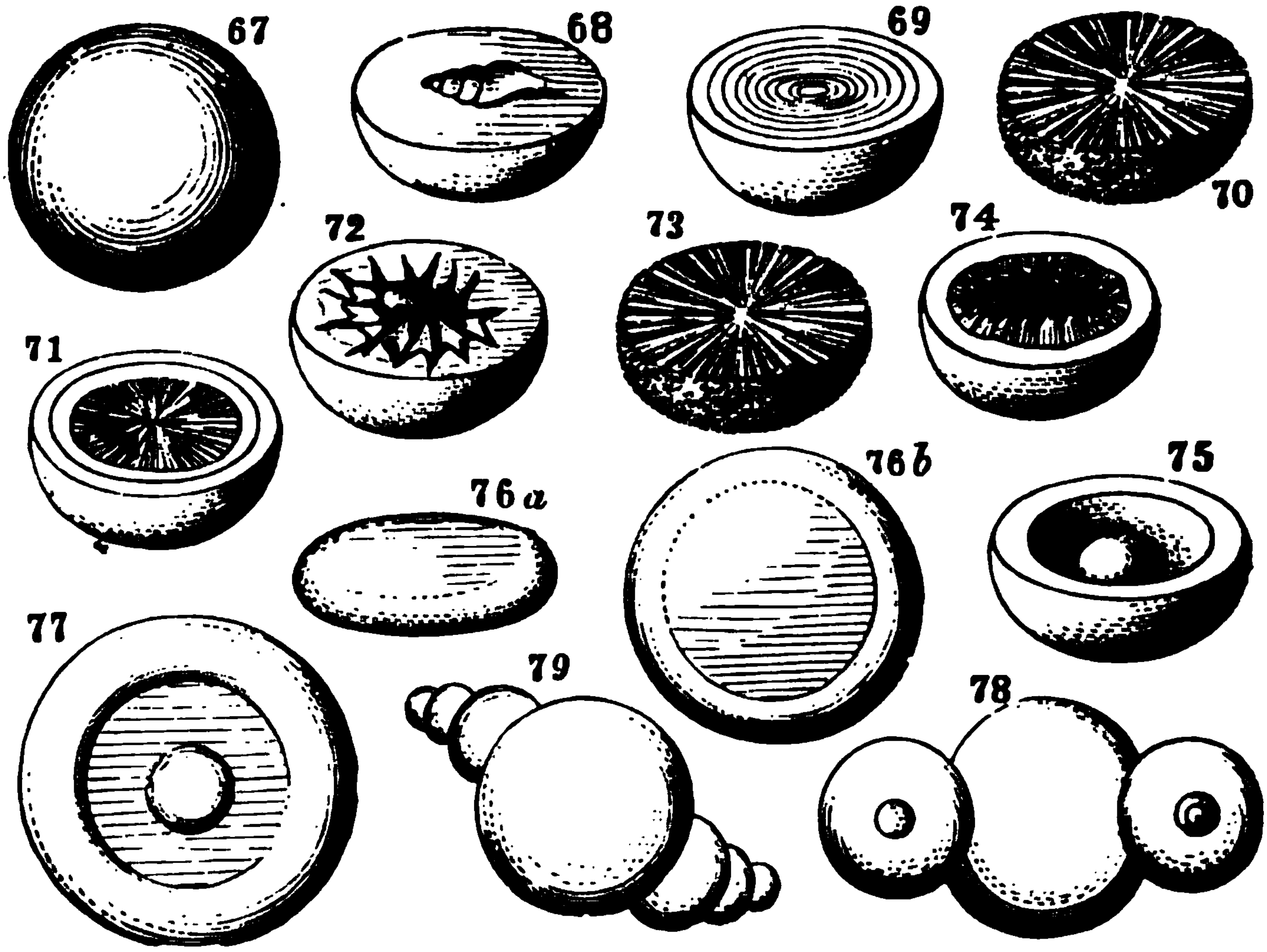
102. (2.) **Kinds of structure not properly a result of deposition, and mostly of subsequent origin.**—The kinds of structure here

included are (*a*) the *concretionary*, (*b*) the *jointed*, and (*c*) the *slaty*. They are produced either in the process of consolidation or during subsequent changes.

103. *a*. The *Concretionary Structure*.—This kind of structure has been briefly explained in § 80, and is here further illustrated.

Fig. 67 is a sphere,—a very common form. The sphericity is frequently as perfect as in a bullet or cannon-ball, though usually more or less ovoidal, and sometimes quite distorted. The size varies

Figs. 67–79.



from a mustard-seed and less to a foot or more; and generally those that are together in a layer of rock approach a uniformity in size. They often have a shell, or a fragment of a plant, or some other object, at the centre. In other cases they are hollow and filled with crystals. The structure is often in concentric layers.

Figs. 68 to 75 are views of sections showing the interior. In 68 there is a fossil shell as a nucleus; in some cases a fossil fish forms the interior of a concretion.

The structure in fig. 68 is represented as solid without concentric layers. In fig. 69 the structure is concentric, the layers either firmly adherent or easily separating. In 70 a variety with a radiated structure is shown, consisting of crystalline fibres diverging from the centre and showing crystalline apices over the exterior surface. In fig. 71 the exterior is concentric but the interior is filled with radiated crystallizations.

In fig. 72 the interior is irregularly cavernous, as if it had cracked thus in drying. In fig. 73 there is a similar result, but with more numerous and smaller cracks, making a reticulation of them; and when these cracks are subsequently filled by carbonate of lime, heavy spar, or other material, by a process of infiltration, it becomes a kind of *septarium*, and forms frequently a beautiful object when polished. Some flattened concretions of this kind are a yard in diameter. In 74 the interior is irregularly hollow, and filled around with a layer of crystals (quartz crystals are the most common in such a condition), forming what is called a *geode*,—a little crystal grotto. In fig. 75 the concretion is hollow and contains another small concretion. This variety is not uncommon. They rattle in the hand when shaken.

Fig. 76 *a*, *b* are different views of flattened or disk-shaped concretions; 77 is another, approaching a ring-shape; 78, a combination of three flattened concretions; 79, another, which is remarkable for the symmetry of its compound form while so irregular.

Fig. 80.

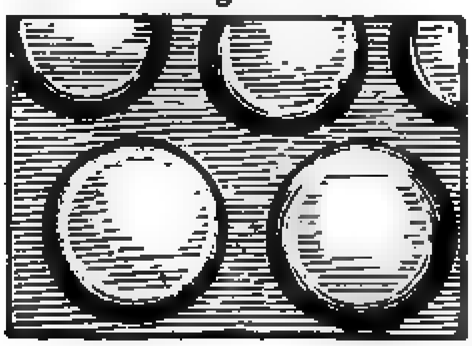


Fig. 81.

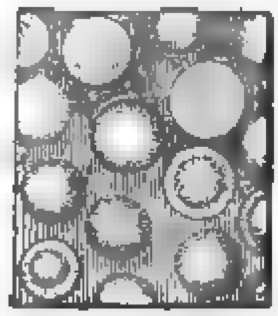


Fig. 80 is part of a clay layer made up of flattened concretions. A concretionary layer often graduates insensibly into one in which no concretions are apparent, through the coalescence of the whole. Fig. 81 represents a rock made up of concretions of the size of peas,—a calcareous rock called *pisolite* (from *pisum*, a *pea*). Each concretion has a concentric structure, the layers easily peeling off. The oolite (named from ὠόν, egg) is similar, except that the concretions are as small as the roe of fish, or even as fine as grains of sand.

Fig. 82.

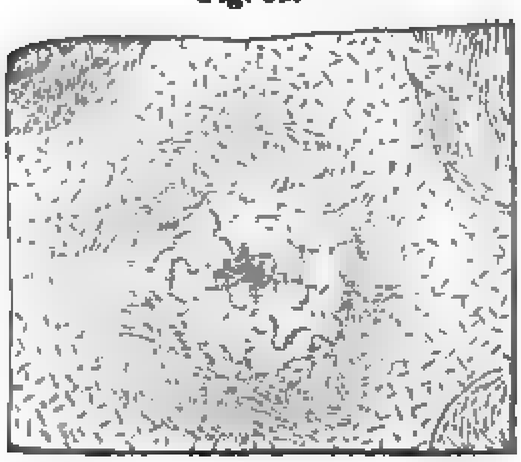
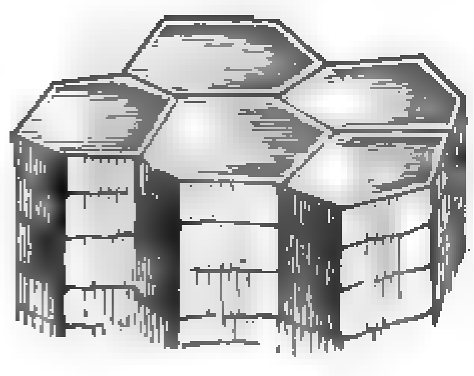


Fig. 83.



104. Fig. 82 exhibits a crystalline rock with spherical concretions imbedded in its mass and not separable from it,—each layer (of the three represented

in each concretion) consisting of different minerals: for example, *garnets* characterizing the centre, *feldspar* the middle layer, and *mica* the outer; and all making a solid mass. The constitution of such concretions is very various. In rocks containing feldspar they usually consist largely of feldspar, and sometimes of feldspar alone, or of feldspar with some quartz. The concretions in pitchstone and pearlstone (called *spherulites*) are almost purely feldspathic, and often separate easily from the rock.

105. Fig. 83 represents basaltic columns, like those of the Giants' Causeway, having the tops concave: at each joint in the columns, in such a case, there would be the same concavity, a convex and concave surface fitting neatly together like a ball-and-socket joint. This tendency to break with concave or convex surfaces is another example of concretionary structure; and in the example referred to, each column is an independent line of concretionary solidification distinct from the others. This concretionary structure is often wholly unobservable in the solid unaltered rock. But let it begin to decompose by atmospheric agencies, and concentric or successive concave layers become apparent; and sometimes they are so perfectly developed as to separate easily and afford thin plates, or an imperfectly slaty structure.

106. In some granite and sandstone, decomposition develops in like manner a concretionary structure. The rock, after partial alteration, peels off in concentric layers, and a bluff of granite which has undergone the change sometimes appears as if made up of huge rounded boulders piled together, with earth or crumbling rock between; in fact, each of the masses resembling boulders was the centre of a concretion. A sandstone often looks like an excellent stone for buildings, which, after an exposure of a few months, will fall entirely to pieces. Complete immersion in water is often a protection to such stone; and they may frequently be used architecturally for submarine purposes when not fit for structures out of water.

Fig. 84.

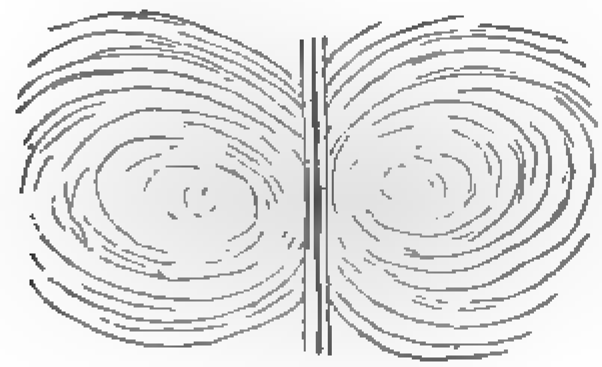
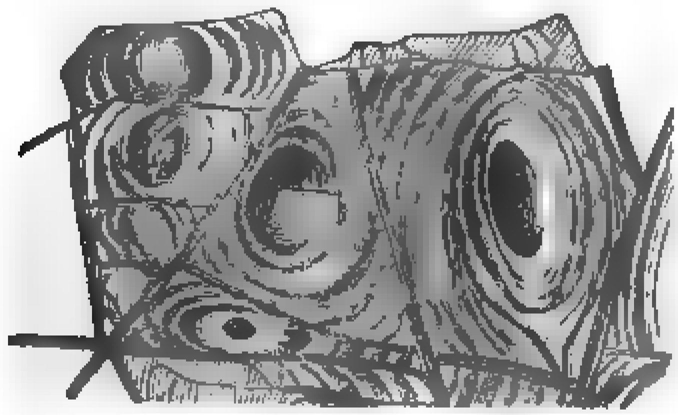


Fig. 84 is a case of concretion in a sandstone alongside of a small fissure, observed in Australia. The two concretions measured twenty feet across. They consisted of layers from half an inch to two inches thick, which separated rather easily. The rock elsewhere was without concretions.

Fig. 85 is from an argillaceous sandstone which before consolidation had been intersected by slender mud-cracks, and subsequently, on hardening, each areolet became a separate concretion. The action of the sea had worn the surface and brought the structure out to view.

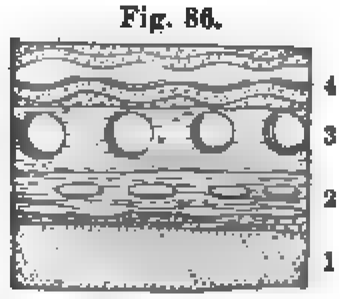
107. The concretions in sandstones are usually spheres or spheroidal, while those in argillaceous layers are flattened disks.

Fig. 85.



In fig. 86 the lower sandstone layer (1) has no concretions; the other (3) contains spherical concretions; in the upper layer (4), an argillaceous sandstone, the concretions are somewhat flattened and coalescent; in the shaly layer (2) they are very much flattened, and in its lower part coalescent.

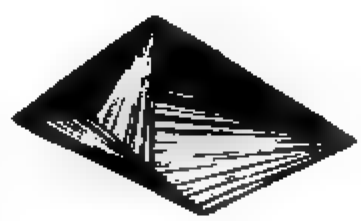
Fig. 86.



Concretions sometimes take fanciful or imitative shapes; and every geologist has had petrified turtles, human bones, skulls, and toads brought him, which were only examples of the imitative freaks of the concretionary process. The turtles are usually what are mentioned as *septaria* on page 95. Occasionally concretions take long cylindrical forms, from consolidation around a hole bored by a worm or mollusk, the hole giving passage to the concreting ingredient; or they derive their form from some rootlet or stem of a plant, in which case they are often branched.

A radiated arrangement is common when no distinct concretions are formed, as with quartz crystals in irregular cavities. Sometimes different points become centres of radiation, producing a blending of distinct radiations, as in fig. 87.

Fig. 87.

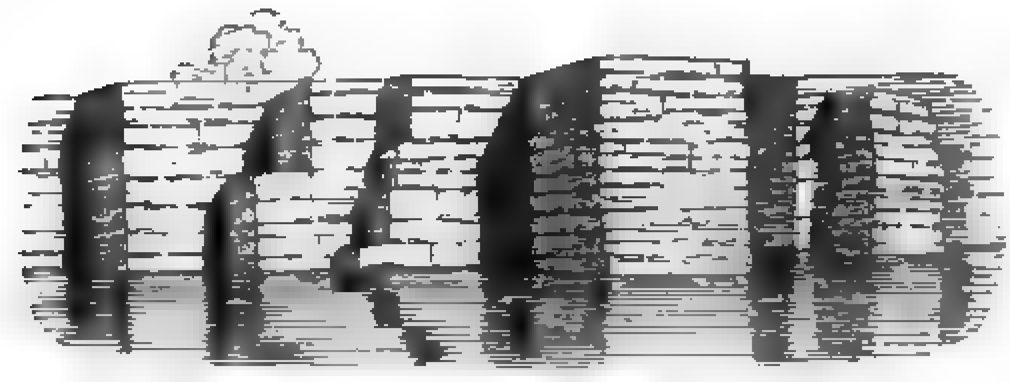


Very many of the mineral species shoot into stellar and globular radiated crystallizations. Others, like pyrites, readily collect in balls or nodules around a foreign body as a nucleus, or, if none is at hand, around the first molecule of pyrites that commences the crystallization. This tendency in nature to concentric solidification is so strong that no foreign nucleus is needed. The iron-ore of coal-regions is mostly in concretions in certain layers of the Coal measures. The rounded masses often lie imbedded in the clayey layer, or are so numerous as to coalesce into a solid bed.

108. *b.* The *Jointed Structure.*—*Joints* in rocks are planes of fracture or division cutting directly across the stratification and extending

through great depths. The planes of division are often as even as if a thin blade had been drawn through with a clean long stroke. These *joints* may be in one, two, or more directions in the same rock, and they often extend, with nearly uniform directions, through regions that are hundreds of miles in length or breadth. The ac-

Fig. 58.



companying sketch represents the falling cliffs of Cayuga Lake, and the fortress-shapes and buttresses arising from the natural joints intersecting the rocks. The wear of the waters from time to time tumbles down an old surface and exposes a new range of structures.

Traversing the surface of a region thus intersected, the joints appear as mere fractures, and are remarkable mainly for their great extent, number, and uniformity. In case of two systems of joints—the case most common—the rock breaks into blocks which are rectangular or rhomboidal according as the joints cross at right angles or not. In some places a layer looks like a rectangular pavement on a vast scale. In others, where the layers are thick and coarse and somewhat displaced, there is a resemblance to artificial fortifications, or cities in ruins, which is quite striking. The main system of joints is usually parallel to the strike of the uplifts, or else to the range of elevations or mountains in the vicinity, or to some general mountain-range of the continent; and the directions are studied with much interest, because of their bearing upon the geological history of the country.

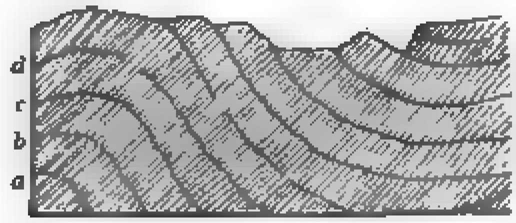
The joints in rocks, when not too numerous, are often a great assistance to quarrymen in quarrying rock, as they afford natural sections of the layers.

109. *c. Cleavage*, or the *Slaty Structure.*—The slaty structure—or cleavage, as it is called—is in some cases parallel with the planes of deposition or bedding of a rock; and such examples of it come under a former head. But in many of the great slate regions, as in that of Wales, the slate-lamination is transverse to the bedding, as shown in

fig. 89, in which the lines *a, b, c, d* show the lines of bedding, and the oblique lines the direction of the slates. Whole mountains have sometimes this kind of oblique or transverse lamination.

The sketch, fig. 89, by Mather, is from the slate region of Columbia county, N.Y.

Fig. 89.



Occasionally the lines of deposition are indicated by a slight flexure in the slates at the spot, as in fig. 90. In other cases there is a thin intermediate layer of quartz rock or limestone which does not partake of the cleavage. Fig. 91 represents an interstratification of clay-layers with limestone, in which the former have the cleavage, but not the latter,—though the limestone sometimes shows a tendency to it when argillaceous. Fig. 92 represents a rock with two cleavage-directions; and 93 a quartzose sandstone which has irregular cleavage-lines. These last two cases show that the jointed structure is but one variety of the cleavage-structure, and that both have the same origin.

Fig. 90.

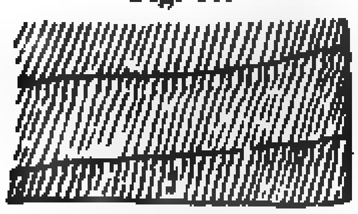


Fig. 91.

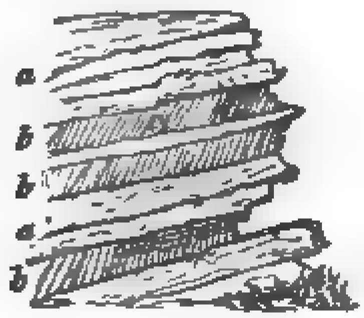


Fig. 92.

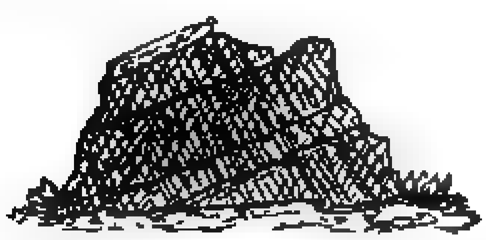
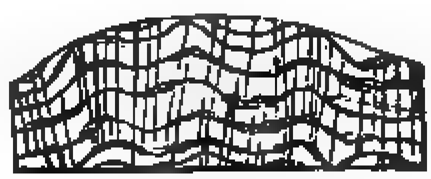


Fig. 93.



Sedgwick first detected the true lines of bedding, and ascertained that the slaty structure was one that had been superinduced upon the clayey strata by some process carried on since they were first deposited.

The foliated structure (or *foliation*) of mica schist, gneiss, and related schistose rocks appears to be sometimes transverse to the bedding, like most slaty cleavage. But, as in the slates, it is not universally so, and the rock in each region requires a special examination with reference to this point.

3. *Positions of Strata.*

110. The natural positions of strata as formed, and the positions resulting from the disturbance or dislocations of strata, are two distinct topics for consideration in this place.

1. **The natural positions of strata as formed.**—Strata in their natural positions are commonly horizontal, or very nearly so. The level plains of alluvium and the extensive delta and estuary flats show the tendency in water to make its depositions in nearly horizontal planes. The deposits formed over soundings along sea-coasts are other results of sea-action; and here the beds vary but little from horizontality. Off the coast of New Jersey, for eighty miles out to sea, the slope of the bottom averages only 1 foot in 700,—which no eye could distinguish from a perfect level. As the processes of the present period along coasts illustrate the grand method of rock-accumulation in past time, it is plain that strata when in their natural positions are very nearly, if not quite, horizontal. Over a considerable part of New York and the States west and southwest, and in many other regions of the globe, the strata are actually nearly horizontal at the present time. In the Coal formation, the strata of which have a thickness, as has been stated, of five to fifteen thousand feet, there is direct proof that the beds were horizontal when formed; for in many of the layers there are fossil trees or stumps standing in the position of growth, and sometimes several of these rising from the same layer. Fig. 94 represents these tilted coal-beds *c, c*, with the stumps *s, s, s*. Since these trees must have grown in a vertical position, or at right angles to the ground, like all others, and as now they are actually at right angles to the layers, and parallel to one another, they prove, whatever the present condition of those layers, that originally they were horizontal. The position of shell-accumulations and coral-reefs in modern seas shows, further, that all limestone strata must have been very exactly horizontal when they were in the process of formation.

Fig. 94.

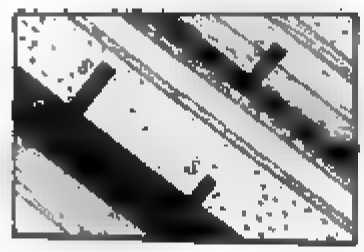
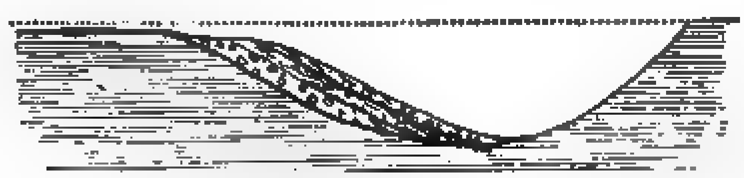


Fig. 95.



In sedimentary deposits, however, some *variation from horizontality* may be produced by the slope of the sea-bottom in certain cases; and off the mouths of rivers in lakes (fig. 95) quite a considerable inclination may result from the fact that the successive layers derived from the inflowing waters would take the slope of the bottom on which they fall. Cases of inclined position from

this cause are necessarily of limited extent, since the conditions required for the result are not such as are likely to exist on a very large scale.

It follows, from these facts, that, unless strata have been disturbed from their natural positions, *the order in which they lie is the order of relative age,—the most recent being highest in the series.*

111. (2.) **Dislocations of strata.**—Strata, although generally in horizontal positions when formed, are in most regions, at the present time, *tilted*, or inclined, and the inclinations vary from a small angle to verticality, or even beyond verticality. They have been raised into folds, each fold often many miles in sweep and equal to a mountain-ridge in extent. They have been crumpled up into groups of irregular flexures, one fold or flexure succeeding to another, till like a series of wrinkles—and necessarily coarse wrinkles—on the earth's surface. Every mountain-region presents examples of these flexures, or uplifts; and most intermediate plains have at least some undulations in conformity with the system in the mountains.

In connection with all this uplifting, there have been fractures on a grand scale; and strata thus broken have been displaced or dislocated by a sliding of one side of such a fracture on the other, through varying distances from a few feet to miles,—one side dropped down to this extent, or the other side shoved up.

The subject, then, of the dislocations of strata is an important one in Geology. The history of the continents and their mountain-ranges, as well as of all their strata, is involved in it.

112. *Uplifts, Folds, Dislocations.*—The following sections illustrate the general facts respecting these uplifts, folds, and dislocations.

Fig. 96.

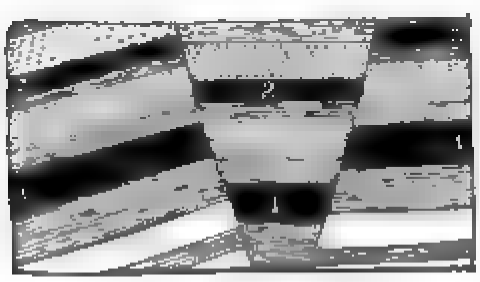


Fig. 97.

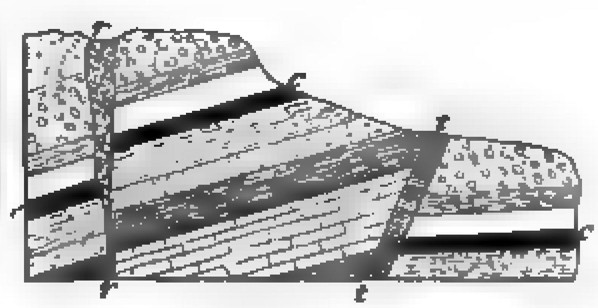
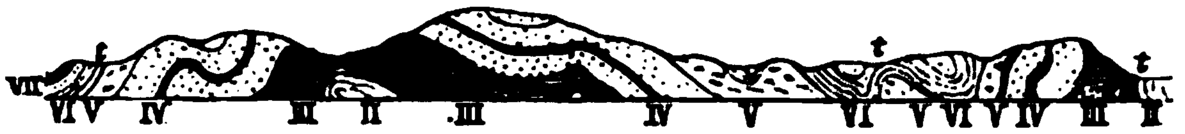


Fig. 96 represents a part of the Coal formation broken and dislocated, the beds (the coal-beds 1 and 2 and the other layers) being changed in direction as well as disjoined in the fracturing. Fig. 97 is another example of similar kind and greater extent. *c* is the

coal-bed. It is broken by the line $t\ t$, which is here a wide fissure filled by rock, and also by $r\ r$, another fissure filled by earth from above. Fig. 98 is an actual section of a part of the Appalachians,

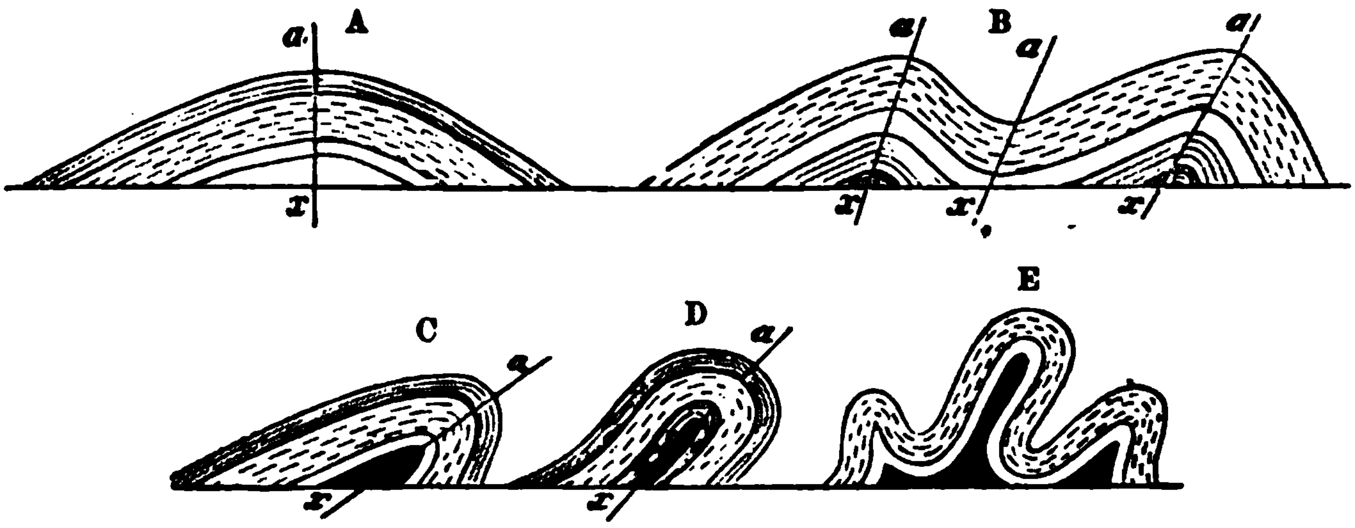
Fig. 98.



six miles in length, showing the foldings and contortions of the strata in those mountains.

Some of the kinds of flexures and curvatures are shown in the

Fig. 99.



annexed figures A–E, to appreciate which it must be understood that these flexures may be each from a few feet to scores of miles in extent, that they form undulations over vast regions, and sometimes make lofty mountains.

The two slopes of a fold may be alike; or, as in B, C, D, one may be much steeper than the other. The line $a\ x$ shows the position of the axial plane of the fold in each case. The ridge-line of a fold may be horizontal, but more commonly it is inclined and reaches gradually its greatest elevation. Moreover, one fold or flexure in the rocks may succeed to another, or they may form interrupted series. Such are some of the various con-

Fig. 100.

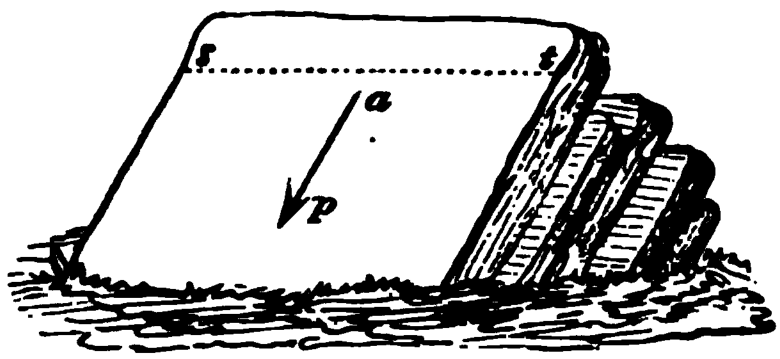
ditions which have been observed, especially in mountainous regions. Fig. 100 represents a section, by Logan, from the Azoic

rocks of Canada. The folded rocks are often overlaid by others of more recent date.

113. In describing the positions of strata, the following terms are used:—

a. Outcrop.—A ledge or mass of rock coming to the surface, or cropping out to view at the surface or above it (fig. 101).

Fig. 101.



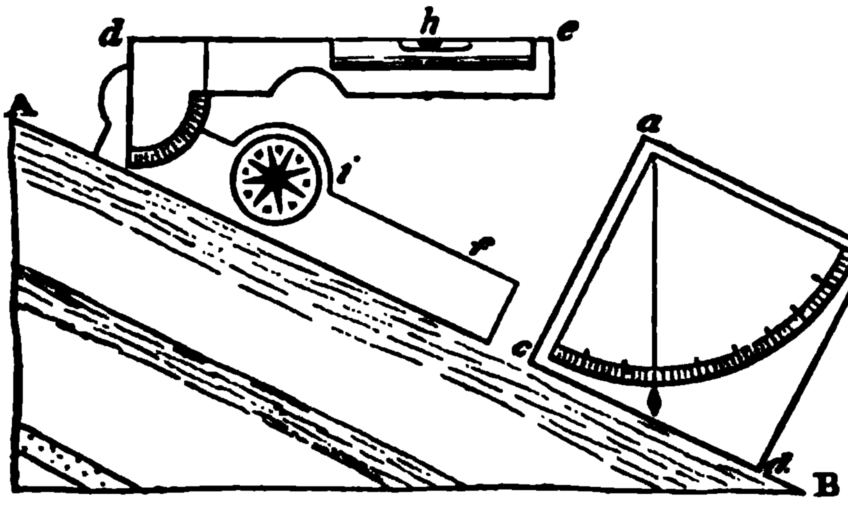
b. Dip.—The slope of the strata, or the angle which the layers make with the plane of the horizon; as *a p* (fig. 101). The *direction of the dip* is the point of the compass towards which the strata slope: for example, the *dip* may be 25° *to the southeast*, or 15° *to the west*, and so on.

c. Strike.—The direction at right angles with the dip, or the course of a horizontal line on the surface of the inclined beds, as *s t*.

The outcropping edges are sometimes called *basset edges.*

d. Anticlinal.—An *anticlinal ridge* is a ridge made of strata sloping in opposite directions, as A, B, C, in fig. 99. An anticlinal axis is the axial or ridge line of such a ridge: it lies in the axial plane *a x*. The word anticlinal is from the Greek *αντι, opposite*, and *κλινω, I incline.*

Fig. 102.



e. Synclinal.—A *synclinal valley* is a valley formed by strata sloping downward from either side, as the middle part of fig. 99 B; and a

synclinal axis is the axial line of the valley, in the plane *a x*. The word is from *συν*, *together*, and *κλινω*, *I incline*.

114. The *direction* of the *strike* is ascertained by means of a pocket-compass, and the *dip* with an instrument called a clinometer. Two instruments of this kind are represented in fig. 102. *a b c d* is simply a square block of wood, with a graduated arc *c b*, the centre of the arc being at a point near *a*. From a pivot at this point a plummet or pendulum is hung. On placing the side *c d* on an inclined plane (A B) the angle is marked off by the position of the pendulum, which of course hangs vertically.

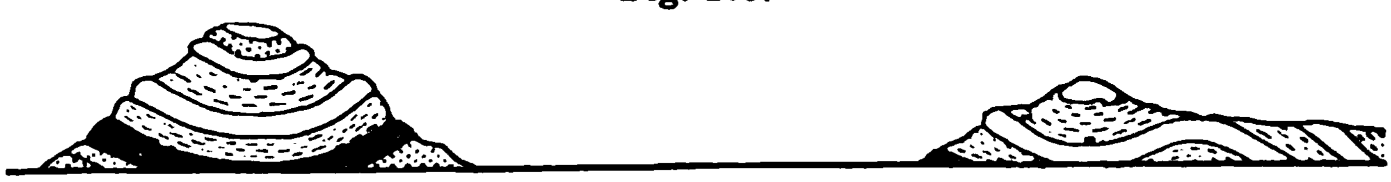
A clinometer of this kind is often combined with a pocket-compass, the pendulum being hung from its centre. This is the most convenient kind of clinometer. If there is a black line marking horizontality across the face of a clinometer of this kind, the angle may be taken by holding the instrument between the eye and the dipping edges that are to be measured, and putting this black line parallel with these edges; the pendulum will mark the angle of dip. In the same manner the slope of the outline of a distant hill or mountain may be measured.

The other clinometer has the form of a foot-rule jointed at the middle. There is a level at *h*, by which the leg *d e* is brought to a horizontal line while the other lies on the inclined plane. The angle between them is read off on a graduated arc near the joint. At *i* a small compass is attached.

In using any clinometer, it is well to place a long strip of board upon the layer of rock, lest the unevenness of surface lead to error.

Faults.—Faults are dislocations of the strata in the plane of a fracture, as seen in the coal-layers, figs. 96, 97; and the amount of fault is the amount of dislocation. We may say, for example, a fault of ten feet, or one thousand feet, or of five miles, and so on, according to the extent of it as ascertained by actual measurement.

Fig. 103.



115. *Complexities in stratified deposits arising from denudation and other agencies.*—By the denuding action of waters, strata are removed over

Fig. 104.

extensive territories, the tops or sides of folds are carried away, and various kinds of sections made of the stratified beds, which are often perplexing to the student.

One of the simplest of these effects is the entire removal of the rocks over wide intervals, so that the continuation of a stratum is met with many miles distant, as in figs. 103, 104.

The result is more troublesome among the flexed or folded strata. A series of close flexures, like fig. 105, worn off at top down to the line *a b*, loses all appearance of folds, and seems like a series of layers

Fig. 105.

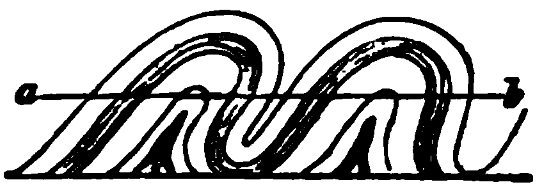


Fig. 106 *a*.

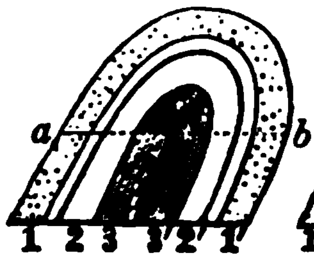


Fig. 106 *b*.

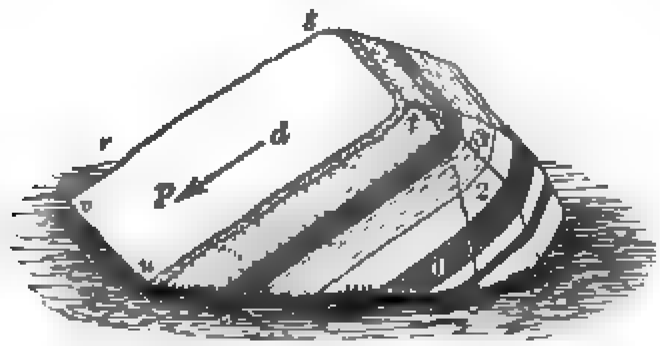
dipping in a common direction. This is best seen from a single fold (fig. 106 *a*). If the part above the line *a b* were absent, the five layers would seem to be a single regular series, with 1 as the top layer, 3, 3′ the middle, and 1′ the bottom one; while the fact is that 1 and 1′ are the same layer, and 3, 3′ is actually a double one. In a number of such folds the same layer which is made two in one fold would be doubled in every other, so that in a dozen folds there would seem to be twenty-four when in fact but *one*. A mistake as to the order of succession would therefore be likely to be made, also as to the number of distinct layers of a kind, and also as to the actual thickness of the middle layer. Instances of a coal-layer doubled upon itself, like 3, 3′, and of others made to appear like many distinct layers, occur in Pennsylvania. On this point special facts are mentioned in the chapter on the Coal formation.

Other effects of denudation are exemplified in the sketch fig. 98. The stratum No. III. is a folded one, with its top partly removed; the layers within a short distance dip in opposite directions. The layer No. IV. to the left is the same with IV. to the right; but they are widely disjoined and very different in direction. Again, V. lies upon the top of the highest summit, nearly horizontally, and in a shallow basin: yet it is part of the stratum V. to the left, which is obviously much folded. The observer finds it necessary to study the alternations of the beds with great care, in order to succeed in throwing into system all the facts in such a region. The coal-regions of Pennsylvania, the whole Appalachians, all New England, and much of Great Britain and Europe, illustrate these complexities arising from flexures and denudation.

116. There is difficulty also in ascertaining the true dip of strata from exposed sections. In fig. 107, *s t u r* is the upper layer of an outcropping ledge of rock, *d p* the line of dip, *s t* the strike. The ledge shows four sections 1, 2, 3, 4. On 1 the edges have the same

dip as *d p*, but on 2, 3, and 4 the angle as obtained from the exposed edges would be different; and on the last the edges would be horizontal, or nearly so. Thus all sections except the one in the direction of the true line of dip (or at right angles to the *strike*) would give a false dip. By finding the surface of a layer exposed to

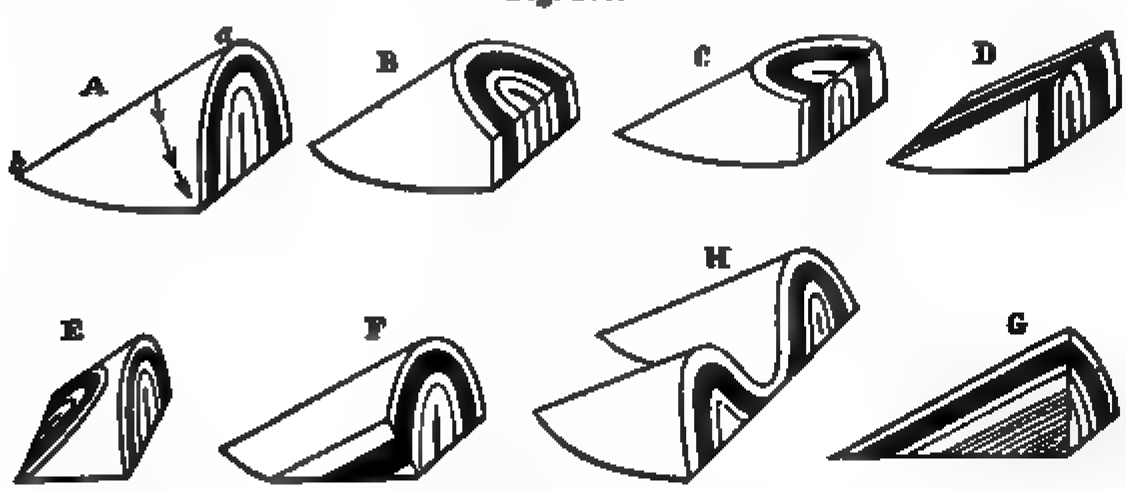
Fig. 107.



view, the true direction of the dip or slope may be ascertained and the error avoided.

117. The following figures (fig. 108) still further illustrate this subject, by showing the variations of direction that may be obtained from the sections of a single folded ridge. For simplicity of explanation, the fold is supposed to be a symmetrical one, though with the ridge-line or anticlinal axis (*a b* in *A*) inclined. In A the section is vertical; but to obtain from the measurement of the exposed

Fig. 108.



edges the true dip, it should have the direction of the arrows, that is, be at right angles to the *strike;* for the layers fold over the ridge in this direction. In B the section is very obliquely inclined; in C it is horizontal, and the edges show nothing of the actual dip; in D the section follows the line of strike; in E it is oblique behind; in F it is an oblique section on one side; and in G a vertical section in the axial plane. All of these sections give wrong results to the clinometer,—a section in the direction of the arrows in fig. A being the only one in which the dip of the exposed edges is the dip of the layers or strata.

If the axis of the fold make a very small angle with the horizon, then the two sides in a horizontal section (such as may result from denudation) will be much elongated (fig. 108 I), instead of short as in fig. C; and if the axis is horizontal the two sides will not meet at all, and the fact of the existence of a fold is not apparent. Even in the former case there might be difficulty in determining the fact of a fold, if the part where the sides unite were concealed from view by the soil or otherwise. But in each case there may be evidence of a fold in the order of the beds in the two sides; for this order on one side would

Fig. 108 I.

be just the reverse of that on the other. If, in fig. I, *c c* represent a coal or iron-ore bed having its border *d* more impure than the rest, this border, if it were on the east side in one half of the fold, would be on the west side in the other half.

The difficulties in the way of correct observation on folded rocks are further enhanced when the axial plane of the fold is inclined,—especially when it is so inclined that both sides of the fold have the same dip (fig. 106 *a*). Still closer study is required when several folds are irregularly combined, as is common in nature.

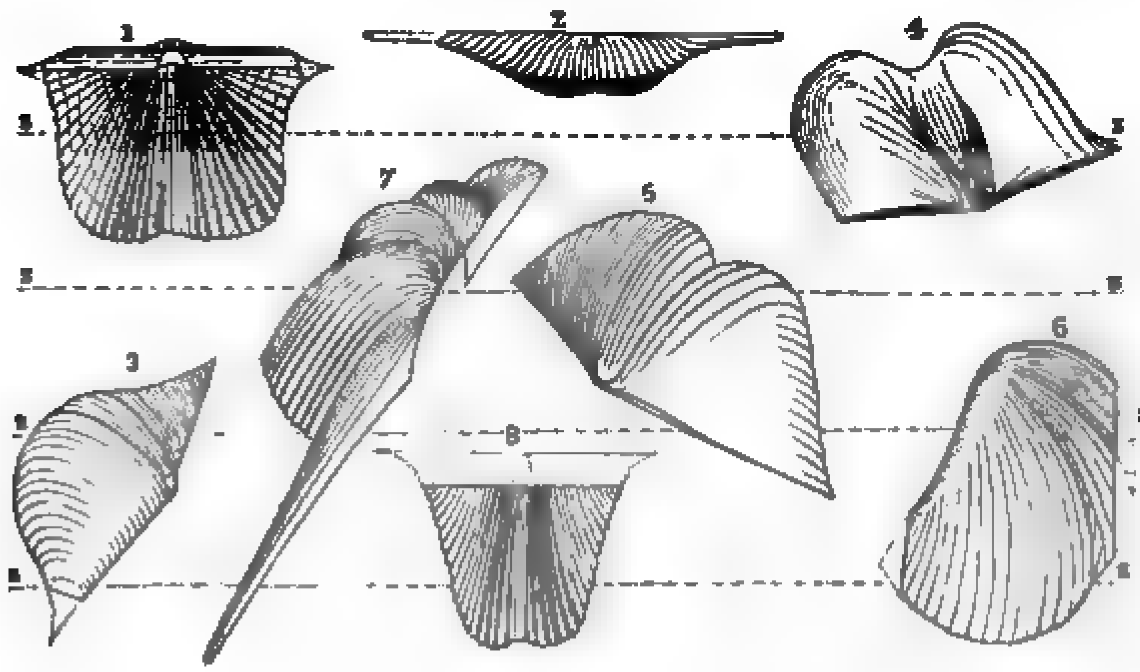
This important subject may be further studied by uniting sheets of different-colored card-board together, bending them into a fold, and then cutting them through in different directions.

118. *Distortions of fossils.*—These uplifts of the rocks, besides disturbing the strata themselves, cause distortion also in imbedded fossils,—either (1) a flattening from simple pressure, or, in addition (2), an obliquity of form, or else (3) a shortening, or (4) an elongation.

The following figures, from a paper by D. Sharpe, illustrate some of these distortions occurring in a slate rock in Wales. They represent two species of shells, the *Spirifer disjunctus* (figs. 1 to 4) and the *Spirifer giganteus* (figs. 5 to 8). Fig. 1 is the natural form of *S. disjunctus*; the others are distorted. The lines *z z* show the lines of cleavage in the slate; 2 lies in the rock inclined 60° to the planes of cleavage, and is shortened one-half; 3 lay obliquely at an angle of 10° or 15°; it is shortened above the middle and lengthened below it; 4 is a cast, the upper part pressed beneath that shown, while the lower is much drawn out; 5 is like 3, the angle with the cleavage-plane being less than 5°; the lower part has lost its plications by the pressure and extension; 6 has a similar angle to the cleavage-plane, but a different position; 7 intersects the cleavage-plane at only 1°, and its lower part is very much prolonged. Compression, a sliding of the rock at the cleavage-planes, and more especially a spreading of the rock itself

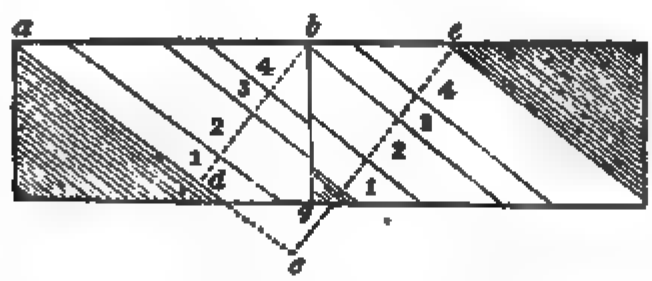
under the pressure, are the causes which have produced these distortions. Univalves and all fossils are liable to become similarly misshapen under the same causes.

Fig. 109.



119. *Calculating the thickness of strata.*—When strata are inclined, as in fig. 110, the thickness is ascertained by measuring the extent along the surface, and also the angle of dip, and then calculating the

Fig. 110.

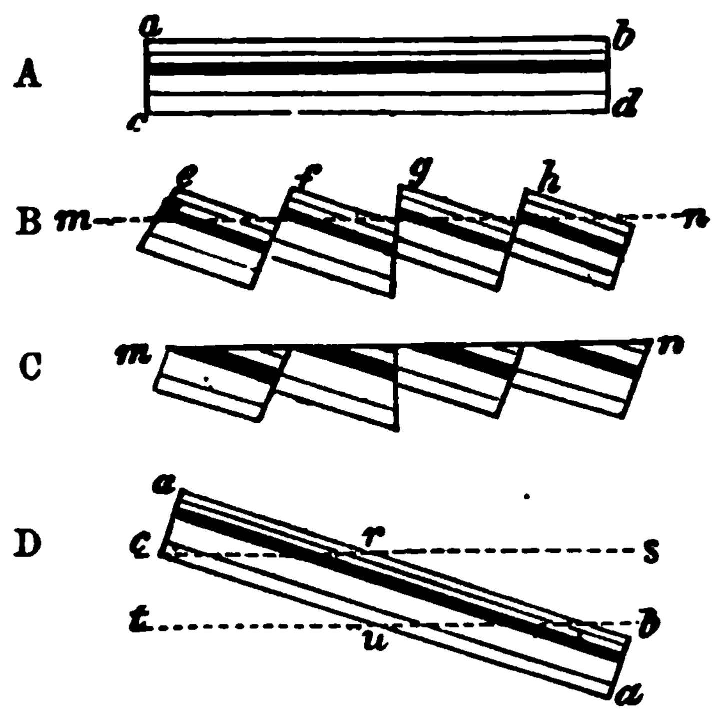


thickness by trigonometry. The thickness of the strata from *a* to *b* is *b d*, the line *b d* being drawn at right angles to the strata. Measuring *a b*, and the dip, which is the angle *b a d*, the angles and hypothenuse of the triangle *a b d* are given to determine one side *b d*. Or with the distance *a e* the side *c e* would be found.

But it is important, for trustworthy results, that the absence of *faults* be first ascertained. The figure (110) represents a fault at *b g*, so that the strata 1, 2, 3, 4 to the left are repeated to the right; and hence the whole thickness is *b d* instead of *c e*. There may be many such faults in the course of a few miles; and each one would increase the amount of error if not guarded against.

120. It is seen from the figure that a single inclined stratum consisting of the layers 1, 2, 3, 4 would have a surface-width (width at the earth's surface or on a horizontal plane) of *a b*. But by means of the fault another portion is brought up to the surface, and *a b* is increased to *a c*. So other faults might go on increasing the extent of the surface-exposure. This is further illustrated in fig. 111. Let A be a stratum 10,000 feet thick (*a* to *c*) and 100,000 feet long (*a* to *b*). Let it now be faulted as in fig. B, and the parts uplifted to a dip of 15°,—taking a common angle for the parts, for the sake of simplicity of illustration. The projecting portions being worn off by the ordinary processes of denudation, it is reduced down to fig. C, *m n* being the surface exposed to the observer. The first error that might be made from hasty observation would be that there were four distinct outcropping coal-layers (calling the black layer thus), instead of *one;* and the second error, the one above explained with regard to calculating the thickness of the whole stratum from the entire length *m n* in connection with the dip. If the stratum were inclined at 15° without faulting, it would stand as in fig. D; and if then worn off to a horizontal surface, the widest extent possible would be *c r*,—less than half what it has with the three faults. The length of *c r* may be determined from the thickness *a c* and the angle of dip, the angles and one side of the triangle being given to find the hypothenuse. With a dip of 15° it would be less than *four-tenths* of *a b*; with a dip of 30°, *one-fifth* of *a b*; with a dip of 45°, less than *one-seventh*.

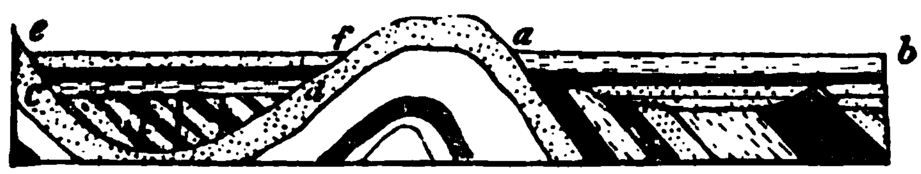
Fig. 111.



It is plain also, without further explanation, that when a layer is folded many times upon itself, as explained on p. 104, a large extent of horizontal surface of tilted beds may be produced even when the stratum thus folded has of itself little thickness.

121. *Unconformable strata.*—Another consequence of the tilting or displacement of strata is this: that deposits are often laid down upon the *upturned* edges of older rocks. Fig. 112 represents cases in which,

Fig. 112.



after the rocks below had been folded or upturned, other strata were laid down at *a b* horizontally on the inclined beds, being thus *uncon-*

formable to those beds. Below *e f* there are really two sets of *unconformable* beds in a synclinal valley; and, moreover, the lower strata were much faulted and upturned before the upper were laid down upon them. The Connecticut River sandstone, like the latter, lies in a synclinal valley of older rocks, is more or less faulted, and is overlaid by horizontal alluvial beds.

There is here exemplified *a method of arriving at the period or time of an uplift.* In such cases of *unconformability*, the upturning of the lower beds must have taken place after they were made, and before the deposition of the overlying beds. The *time of the upturning*, therefore, was between the period to which the upturned rocks belong, and that of the overlying deposits.

Deposits like those at *e f* are true *basin* or *trough deposits*; for they are formed in basins or depressions of the surface. Such deposits may, in general, be distinguished by their thinning out towards the sides of the basin. Yet when synclinal valleys are shallow it is easy, and not uncommon, to mistake beds conformable with the strata below for such basin-formations. The beds *a b* (fig. 113) lie in the synclinal valley *m n* like a basin-deposit, though not so. They were disconnected from the stratum with which they were once continuous, by denudation over the anticlinal axes *m* and *n*. Hence the beds *a b* were formed *before* the folding of the beds, and not *after* it,—an historical fact to be determined in all such cases with great care.

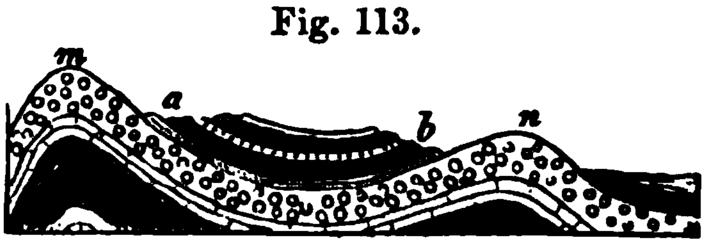


Fig. 113.

4. *Order of arrangement of Strata.*

122. The true order of arrangement of strata is the order in which they were made, or their *chronological order.*

Difficulties.—There are several difficulties encountered in the attempt to make out such an order. The stratified rocks of the globe include an indefinite number of limestones, sandstones, shales, and conglomerates; and they occur horizontal and displaced, conformable and unconformable, part in America and part in Europe, Asia, and Australia, here and there coming to view, but over wide areas buried beneath soil and forests.

Moreover, even the same bed often changes its character from a sandstone to a shale, or from a shale to a limestone or a conglomerate, or again to a sandstone, within a few scores of miles, or, if it retains a uniform composition, it changes its color so as not to be recognized by the mere appearance. Again, some strata are of very limited extent, while others spread widely over a continent.

Again, a stratum of one age may rest upon any stratum in the whole of the series below it,—the Coal measures on either the Azoic, Silurian, or Devonian strata; and the Jurassic, Cretaceous, or Tertiary on any one of the earlier rocks, the intermediate being wanting.

In addition, denudation and uplifts have thrown confusion among the beds, by disjoining, disarranging, and making complex what once was simple. In the United States, many a sandstone in New York and Pennsylvania is represented by a limestone in the Ohio and Mississippi valleys,—that is, the two were of cotemporaneous origin; some rocks in eastern New York are not found in the western part of that State, and some in the central and western not in the eastern. The Post-Tertiary in America in some places rests on Azoic, in others on Silurian or Devonian, in others on Cretaceous or Tertiary. And, if so great diversity of condition exists in one country, far greater may be expected between distant continents.

Amidst all these sources of difficulty, how is the true order ascertained?

123. **Means of determination.**—It is plain from the preceding remarks that the true method cannot consist in grouping rocks of a kind together, as limestones, shales, or sandstones. It is irrespective of kinds, and is founded on a higher principle,—the same which is at the basis of all history,—successiveness in events. The following are the means employed.

(1.) *Order of superposition.*—When strata are little disturbed, vertical sections give the true order in those sections and afford valuable information. Or where the strata outcrop over the surface of a country, the succession of outcropping layers affords a section, and often one of great range. The vertical extent of such a section may be ascertained as explained in § 119. In using this method by superposition, several precautions are necessary.

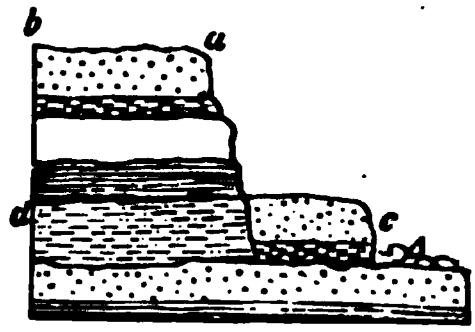
Precaution 1st.—Proof should be obtained that the strata have not been folded upon one another, so as to make an upper layer in any case a lower one in actual position (see p. 107),—a condition to be suspected in regions where the rocks are much tilted, but not where the tilting is small.

Precaution 2d.—It should be seen that the strata under examination are actually continuous.

A fault in the rocks may deceive; for it makes layers seemingly continuous which are not so. In some cases, beds forming the upper part of a bluff (as *a b*, fig. 114) have settled down bodily (*c*) to the bottom, so as to seem to be continuous with the older

ones of the bottom (as *c* with *d*). In one instance a mistake was thus made with respect to the age of a human relic, which a little care might have avoided. In other cases, caverns in rocks have been filled through openings from above, and the same kind of mistake made. When the continuity can be established, the evidence may sometimes lead to important results. For example, it may be found that a coal-bed followed for some miles to one side or the other is continuous with a clay shale, and both are actually one layer; that a sandstone is one with a limestone a few miles off; that an earthy limestone full of fossils is identical with a layer of white crystalline marble in a neighboring district; or that a fossiliferous shale of one region is the same stratum with the mica schist of another.

Fig. 114.



Precaution 3d.—Note whether the strata overlie one another *conformably* or not.

Precaution 4th.—When one bed overlies another conformably, it does not follow necessarily that they belong to consecutive periods. The Tertiary beds may rest *conformably* on any stratum from the Cretaceous to the Silurian. A range of conformability so continuous is not, however, usual; for disturbances of the strata have been so common in past time that the later rocks are seldom conformable to the older. Among rocks comparatively near in age, however, it is common to find strata wanting, without any break in the conformability.

The criterion mentioned, unless connected with others, gives no aid in comparing the rocks of distant or disconnected regions. For this purpose other means must be employed.

124. (2.) *Color, texture, and mineral composition.*—This test may be used to advantage within limited districts, yet only with caution. There were at one time in geology an "old red sandstone" and a "new red sandstone," and whenever a red sandstone was found it was referred at once to one or the other. But now it is well understood that the color is of little consequence, except within a small geographical range. The same general remark holds with reference to mineral composition.

One inference from the constitution of a stratum is safe; that is, that the stratum is more recent than the rock from which its material was derived. Hence an imbedded fragment of some known rock may afford important evidence with regard to the age of the containing stratum.

It is common to judge of the age of igneous rocks by their composition; but it is an unsafe criterion. Some use may be made of it hereafter in settling cases that remain doubtful, but not until the age of the greater part of such rocks has been ascertained on evidence of a better kind than this. In the case of metamorphic rocks of different ages it may prove of value when their distinctive peculiarities are thoroughly known.

125. (3.) *Fossils.*—This criterion for determining the chronological order of strata takes direct hold upon time, and, therefore, is sure and sufficient. *The life of the globe has changed with the progress of time. Each epoch has had its peculiar species.* Moreover, the succession of life has followed a grand law of progress, involving under a single system a closer and closer approximation in the species, as time moved on, to those which now exist. It follows, therefore, that

Identity of species of fossils proves approximately identity of age.

The change has not consisted in a change of species alone, but also in certain grand modifications of type or structure. Thus, for fishes there are both ancient and modern types; and in most of the classes there are great groups which belong to the past and mark the progressing ages,—as Trilobites mark the Palæozoic, Sigillariæ the Coal period, Ammonites and flying reptiles the Reptilian age. Hence the canon may have the broader form,—

Identity of type or family in organic forms proves identity of age.

The canon is a universal one. Had we a table containing a list of the complete series of rocks, and of the families, genera, and species of fossils which each contains, it would be a key for the rocks of the whole world,—South and North America as well as the Orient; and by comparing the fossils of any rock under investigation with this key, the age would be approximately ascertained. This is the method now pursued in studying the geology of the globe. The key is, in fact, already so complete that it is constantly appealed to by the geological observer. The list which is made for the Silurian and Devonian rocks in New York State is used for identifying the strata of the Mississippi basin; and that which has been prepared in Europe is constantly employed to make out the true synchronism between the rocks of the two continents.

By such comparison of fossils it was discovered that the Chalk formation exists in the United States, although there is no *chalk* on the continent; that the Coal formation of North America and that of Newcastle, England, belong to the same geological age; and so in numberless other cases of identity between the strata of distant continents.

The commencement in the preparation of such a key was attended

with much difficulty. In New York State it was necessary—first to study all the sections in the eastern, central, and western parts, and determine carefully the fossils in each stratum; then to compare the sections with one another: when any case of identity in the fossils among these strata of the different sections was observed, it was set down as one horizon determined. By this method, and other aid from observing the continuity of beds, one horizon after another was ascertained, and the strata between were arranged according to their true order of succession.

There are precautions required in the use of this key, depending on individual differences in the continents and diversities in the range of fossils, which will be better understood after a review of the general progress of life on the globe.

126. **Subdivision into Ages.**—By the means explained, great progress has been made in arranging the rocks of the different continents in a chronological series. North America has some large blanks in the series, which in Europe are filled; and in this way various countries are contributing to its perfection. This series has been divided into Ages, based on the progress of life, as follow:—

I. AZOIC AGE (from *a, privative,* and *ζωον, animal*).—Containing no traces of animal life.

II. SILURIAN AGE, OR AGE OF MOLLUSKS.—Mollusks the dominant race.

III. DEVONIAN AGE, OR AGE OF FISHES.—Fishes the dominant race.

IV. CARBONIFEROUS AGE, OR AGE OF ACROGENS.—Characterized by coal-plants, or Acrogens.

V. REPTILIAN AGE.—Reptiles the dominant race.

VI. MAMMALIAN AGE.—Mammals the dominant race.

VII. THE AGE OF MAN.

The subdivisions are given beyond.

127. *Thickness of the stratified rocks.*—The whole thickness of the rocks in the series has been stated at fifteen or sixteen miles. But this includes the sum of the whole grouped in one pile. As the series is nowhere complete, this cannot be said to be the thickness observed in any one region. The rocks of New York, down to the Azoic, counting all as one series, are about 13,000 feet in thickness. They include only the Silurian and Devonian (excepting the Triassic in the southeast). To the north they thin out to a few feet, while they thicken southward towards Pennsylvania. In Pennsylvania the rocks include the Carboniferous, and the whole thickness is at least 40,000 feet. This is exclusive

of the Triassic, which may add a few thousands to the amount. In Virginia the thickness is still greater; but no exact estimate has been made. In Indiana and the other States west it is only 4000, although extending, as in Pennsylvania, to the top of the Carboniferous. The greater part of the continent of North America east of the Mississippi is destitute of rocks above the Carboniferous.

In Europe the rocks of the later periods are far more complete than in North America, while the older also, according to the estimates stated, exceed the American. In Great Britain the thickness to the top of the Carboniferous is over 60,000 feet, and from the Carboniferous to the top of the series little less than 10,000 feet more. This amount is the sum of the thickest deposits of the several formations, and not the thickness observed in any particular place.

2. UNSTRATIFIED CONDITION.

128. The larger part of the crystallized rocks are sedimentary rocks altered or crystallized by heat or other means; and they are, therefore, not true examples of unstratified rocks. In general they still retain the lines of deposition distinct. When gneiss and mica schist are found in alternations with one another, it is plain that each layer corresponds to a separate layer in the original deposit, and the beds, although crystalline, are still as really stratified as they ever were.

In some metamorphic rocks, however, the appearance of stratification is lost; and such may be properly said to be unstratified. Yet it should be understood that the name does not imply that they never were stratified, but that this is now their apparent condition. Granite and syenite are unstratified rocks of this kind. In much granite there is no lamination, no arrangement of the constituent minerals in parallel planes, no evidence of subdivision into layers. But even this true granite, a few miles off, may become a schistose or gneissoid rock, and, a short distance farther on, by gradual transition, a gneiss in which a schistose structure is very distinct.

Examples of the unstratified condition are common among true igneous rocks. The ridges of trap or dolerite which range in lofty masses over many districts—as the Palisades on the Hudson, Mounts Tom and Holyoke and other trap ridges of the Connecticut valley, the trap of the Giants' Causeway and of Fingal's Cave—are some of these examples. The rocks were melted when they came up to the light through fissures, and they now stand without any

marks of stratification. The sketch below represents a scene among rocks of this kind in Australia. The dome-shaped masses of

Fig. 115.

Basaltic columns, coast of Illawana, New South Wales.

trachyte in some regions of ancient volcanoes, and the interior mass of many great volcanoes,—sometimes exposed to view through rendings of the mountain or denudation by water,—are also examples. But the ordinary outflows of liquid rock from volcanoes usually produce layers, which are covered afterwards by others in succession; and volcanic mountains, therefore, have to a great extent a stratified arrangement of the rock-material, and not less perfectly so than bluffs of stratified limestone. Moreover, the same rock which forms the Giants' Causeway may in other places be interstratified among sandstones and shales; for the layer of igneous outflow, wherever it takes place, may be followed afterwards by deposits of sand or other sediment.

129. Another example of unstratified material is found in the loose pebbles and stones which cover a large part of the northern half of both the American and European continents. Any ordinary mode of action by water lays down sediments in layers. But these accumulations—often called *drift*—are of vast extent and without layers. Wherever the same kind of material is in layers, it is then said to be stratified; and thus it is distinguished from the *unstratified*.

There may, therefore, be both stratified and unstratified sediments, and stratified and unstratified igneous rocks; and by the obliteration of the planes of deposition by metamorphism there may be unstratified metamorphic rocks like granite, as well as stratified.

130. On the subject of the structure of these rocks, it is only necessary to refer to the ordinary massive structure of granite

and trachyte, etc., and to the columnar structure met with among igneous rocks. The last is represented in the figure given above. There are all shades of perfection in this columnar structure, from prisms of great height with perfectly plane sides, to a mere tendency to split in prismatic forms; and also from this less perfect prismatic character, to the massive structure with no trace of columnar fracture.

For a continuation of this subject, see the chapter on igneous operations, under Dynamical Geology.

131. (1.) **General nature of veins.**—*The vein condition.*—Veins are narrow plates of rock intersecting other rocks. They are the fillings of cracks or fissures; and, as these cracks or fissures may either extend through the earth's crust to the interior and divide it for long distances, or reach down only for a limited depth, or be confined to single strata, so veins are exceedingly various in extent. They may be no thicker than paper, or they may be scores of rods in width, like the great fissures opened at times to the earth's inner regions by subterranean agency. They may be clustered so as to make a perfect net-work through a rock, or may be few and distant. And, as strata have been faulted, so veins also may have their faults or displacements. All those subterranean movements that produce joints and fractures in rocks may give origin to veins.

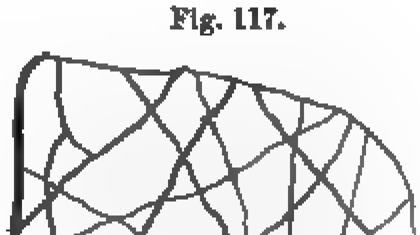
(2.) **Subdivisions.**—Veins are divided into *dikes* and proper *veins*.

Dikes are filled by volcanic rocks, basalt, trap, or some other igneous rocks, and have regular and well-defined walls.

Veins are occupied by quartz, granitic rocks, metallic ores, calcite, fluor spar, heavy spar, etc.,—ingredients which are less obviously a liquid injection from below, and probably never of this nature. They are generally irregular in form, often indistinct in their walls, and very varying in their ingredients. They abound

Fig. 116.

Fig. 117.



in regions of metamorphic rocks. Veins have been subdivided into kinds; but the divisions need not here be considered.

(3.) **Forms and faults of veins and dikes.**—Fig. 116 represents two simple veins or dikes (*a a* and *b b*) intersecting stratified rocks.

Fig. 117, a net-work of small veins.

Fig. 118.

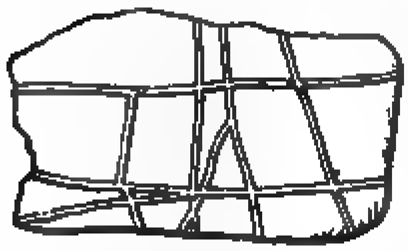


Fig. 119.

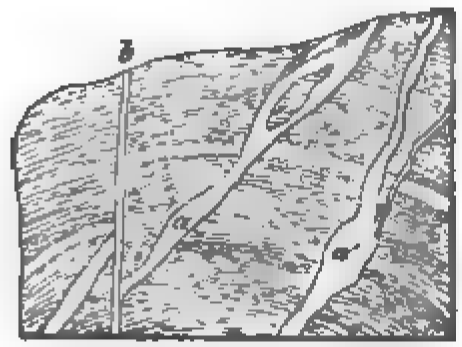


Fig. 118, small veins of quartz intersecting gneiss,—the mass five feet square. The veins do not all cross one another, and correspond to the cracks which result from contraction, as by sun-drying or cooling, rather than to those of any other mode of fissuring.

Fig. 119. Two veins *a a'*, presenting some of the common irregularities of mineral veins in size, the enlarged parts containing mostly the ore: *a* is faulted by another vein *b*, which is of subsequent formation.

Fig. 120.

Figs. 120, 121, 122. Examples of granitic veins of very large size in a gneissoid granite, showing their subdivisions and various irregularities (taken

by the author from granitic rocks near Valparaiso). The veins undergo constant changes of size, and in some places encircle masses of rock resembling

Fig. 121.

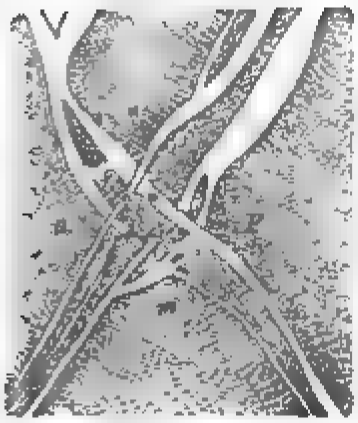
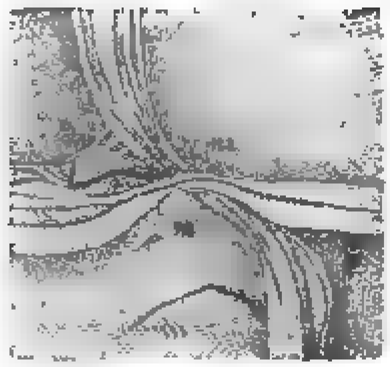


Fig. 122.



the rock outside. The rock adjoining the vein is more micaceous than that at a distance, and the direction of the lamination (as indicated in the figures) varies with some reference to the intersecting veins, curving approximately parallel to the veins on two opposite sides *m* and *n*, and not at all so on the other two *o* and *p*. The subdivisions of the veins in fig. 121 cross one another in an alternate manner, *a* cutting *d* and *e* but cut by *c*, and *b* cut by *c*, *d*, and *e*; and in 122, although the veins are similar in constitution, one cuts the other; and in 120 the two crossing veins are broken and subdivided at the intersection so as to appear like one vein stretching off in two directions like a letter X.

Fig. 123.

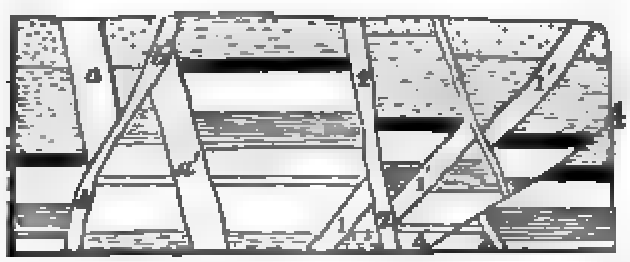


Fig. 123. A vein *a* faulted by *b*,—whence it is inferred that *b* is subsequent to *a* in age. Also a vein 1 faulted by 2 and again by 3, and 3 faulted

Fig. 124.

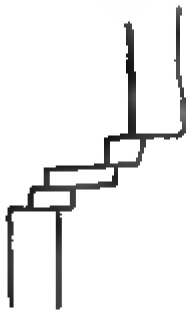


Fig. 125.

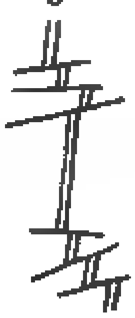


Fig. 126.

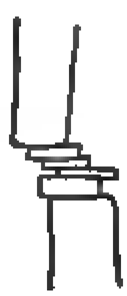
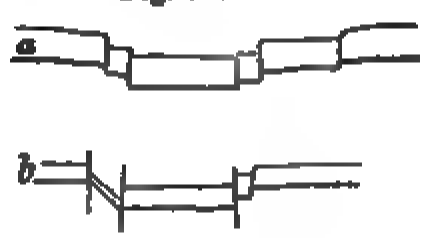


Fig. 127.

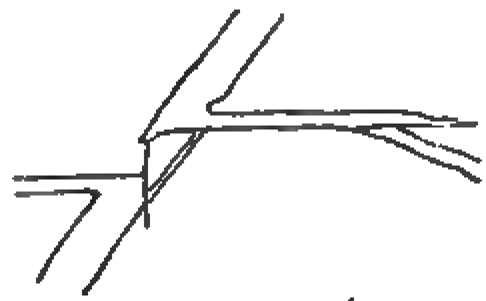


by 4: 2 and 3, therefore, were subsequent in age to 1, and 4 was subsequent to 3. The faulting is exhibited also in the layers of the stratified rocks which the veins intersect.

Figs. 124, 125, 126. Veins much broken or faulted: in 124, four faults within a length of eighteen inches; in 125, six faults in six feet; in 126, the broken parts of the vein of unequal breadth.

Fig. 128.

Fig. 129.



Figs. 127, 128, 129. Other faulted veins, 127 *a* and *b*, six feet apart, and still different in their faults; 128, 129, other interrupted veins. These dissimilarities between the parts of one faulted vein, as in 126, and between the parts of two parallel veins, as in 127, arise from an oblique shove of the parts either at the time of the fracturing in which the veins themselves originated, or at some subsequent fracturing.

The points here illustrated are,—

The great irregularities of size in veins along their courses, swelling out and contracting; their occasional reticulations; their frequently embracing portions of the enclosed rock; their numerous faultings or breaks and displacements.

132. (4.) **Structure.**—*Dikes.*—Dikes consist essentially of the same kind of material from side to side and at all heights, where not altered by exposure to the air. The structure may be simply massive, or cracked irregularly, as in many volcanic dikes. But frequently there are transverse fractures, producing a columnar structure, so that a dike is like a pile of columns. For a short distance from the walls the structure is generally imperfect (fig. 130); and in many cases there is an earthy layer along the sides, or even a laminated structure parallel with the walls (fig. 131), produced by the friction of the rising liquid mass against the walls of the fissure.

Fig. 130.

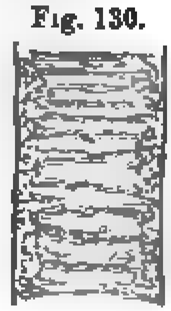
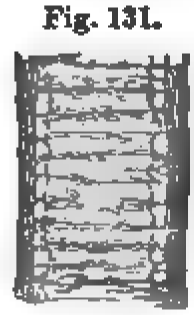


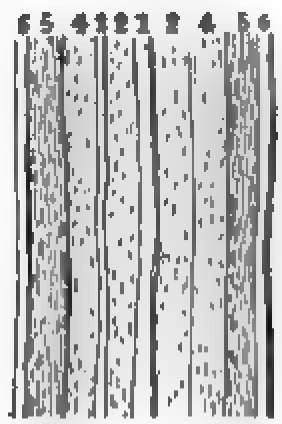
Fig. 131.



133. *Veins* never have the transverse columnar structure of dikes. The simplest consist of one kind of material,—as quartz, granite, heavy spar,—and are alike from side to side. But others have a banded structure not found in dikes, consisting in an arrangement of the material parallel to the walls. Fig. 132 represents such a vein, consisting of eleven bands: 1, 3, and 6 are

bands of quartz; 2, 4, of a gneissoid granite; and 5, of gneiss. Of banded veins, the simplest is a vein with three bands, one central; but the number may be a score or more.

Fig. 132.



Instead of being simply rock-material, as in fig. 132, the bands may be partly metallic ores of different kinds, and calcite, heavy spar, fluor spar, may make the alternating bands instead of granite or gneiss. A great vein at Freiberg consists of layers of blende, quartz, fluor spar, pyrites, heavy spar, calcite, each two or three times repeated, the layers nearly corresponding on either side of the middle seam.

Thus this banded structure is as much characteristic of veins as the columnar structure is of dikes: each fails of the peculiarity in their simpler kinds.

The bands of a vein are far from uniform at different heights, even when the width of the vein is constant; and they vary exceedingly through the contractions and expansions which take place at intervals. The expanded portions may alone be banded, or consist of layers parallel to the sides, or contain ore.

The mineral or rock-material accompanying the ore in a vein is called the *vein-stone*, or *gangue*. The most common kinds of vein-stone are quartz, calcite, barytes, and fluor.

In studying veins, besides noting their extent, mineral character, and structure, it is important to ascertain their strike and angle of dip. There is generally an approximate uniformity of strike in a given region; and frequently the direction is parallel to the principal line of elevation in the region. The nature of the walls or adjoining rock, and systems of faults, are other points that should receive close attention.

134. *False veins.*—Besides the veins and dikes described, there are also *false veins*. These false veins are fissures filled by sand or clay from above. They are readily distinguished by the sedimentary nature of the material; for all true dikes or veins are occupied by crystalline rocks or minerals. In a similar manner earth and organic remains may be washed into caverns or any open spaces in rocks, and so make, in the very body of an old record, a false entry. Such a conjunction of comparatively modern fossils with more ancient may lead to error, unless the facts are carefully studied and the true explanation ascertained.

In the language of miners,—

A *lode* is a vein containing ore.

The *hanging wall* of a vein is the upper wall when the vein has an oblique dip; and the opposite is the *foot-wall.*

The *fluccan* is the half-decomposed rock adjoining a vein; and a thin, clayey layer along either side of a vein is called the *selvage.*

A *horse* is a body of rock, like the wall-rock, occurring in the course of a vein.

A *comb* is one of the layers in a banded vein,—so called especially when its surface is more or less set with crystals.

PART III.

HISTORICAL GEOLOGY.

GENERAL DIVISIONS IN THE HISTORY.

1. **Nature of subdivisions in history.**—The methods of ascertaining the true succession or chronological order of the rocks have been explained in §§ 122–125, and in connection (§ 126) a brief mention is made of the grander divisions of the series. Some further explanations are necessary as introductory to the survey of geological history.

What are subdivisions in history?—Many persons, in their study of geology, expect to find strongly-drawn lines between the ages, or the corresponding subdivisions of the rocks. But geological history is like human history in this respect. Time is one in its course, and all progress one in plan.

Some grand strokes there may be,—as in human history there is a beginning in man's creation, and a new starting-point in the advent of Christ. But all attempts to divide the course of progress in man's historical development into ages with bold confines are fruitless. We may trace out the culminant phases of different periods in that progress, and call each culmination the centre of a separate period. But the germ of the period was long working onward in preceding time, before it finally came to its full development and stood forth as the characteristic of a new era of progress. It is the same with the development or history of an individual being. There are distinct epochs and periods in the history which all recognize,—the period of the embryo, of the youth, of the adult. But no one thinks of marking the hour or day when one ends and another begins, or of pointing to a visible physical line that at any given moment was passed. It is all one progress, while successive phases stand forth in that progress.

In geological history, the earliest events were simply physical.

While the inorganic history was still going on (although finished in its more fundamental ideas), there was, finally, the introduction of *life*,—a new and great step of progress. That life, beginning with the lower grades of species, was expanded and elevated through the creations of new types, until the history closed in the appearance of Man. In this organic history there are successive phases of progress, or a series of culminations, with the creation of Man and Mind as the last and loftiest of these culminations. As the tribes, in geological order, pass like panoramic scenes before us, the reality of one age after another becomes strongly apparent. The age of Mammals, the age of Reptiles, and the age of Coal-Plants come out to view like mountains in the prospect,—although if the mind should attempt to define precisely where the slopes of the mountain end as they pass into the plain around, it might be greatly embarrassed. It is not in the nature of history to be divided off by visible embankments; and it is a test of the true philosopher to see and appreciate the culminations of phases in time, or of the successive ideas in the system of progress, amid the multitude of events and indefinite blendings that bewilder other minds.

We note here the following important principles:—

First. The reality of an age in history is marked by the culmination of some new idea in the system of progress.

Secondly. The beginning of an age will be in the midst of a preceding age; and the marks of the future coming out to view are to be regarded as prophetic of that future.

Thirdly. The end of an age may be as ill defined as its beginning, although its culminant point may stand out boldly to view.

Thus, the age of Coal-Plants was preceded by the occurrence of related plants far back in the Devonian. The age of Mammals was foreshadowed by the appearance of mammals long before, in the course of the Reptilian age. And the age of Reptiles was prophesied in types that lived in the earlier Carboniferous age. Such is the system in all history. Nature has no sympathy with the art which runs up walls to divide off her open fields.

But the question may arise, whether a geological age is not, after all, strongly marked off in the rocks. Rocks are but the moving sands or the accumulations of dead relics of the age they represent, and are local phenomena, as already explained. Each continent has its special history as regards rock-making; and it is only through the fossils in the rocks that the special histories are combined into a general system. Movements have in all ages disturbed one hemisphere without affecting the other, causing breaks in the

succession of rocks in one continent or part of a continent that have no representatives in another.

When an age can be proved, through careful study, to have been closed by a catastrophe or a transition which was universal in its effects, the event is accepted as a grand and striking one in geological history. But the proof should be obtained before the universality is assumed. Hence the conclusion,—

Fourthly. The grander subdivisions or ages in geological history, based on organic progress, should be laid down independently of the rocks. They are universal ideas for the globe. The rocks are to be divided off as nearly as practicable in accordance with them.

Each continent, under these ages, then becomes a special study; and its history has its periods and epochs which may or may not correspond in their limits with those of the other continents. Every transition in the strata, as from limestone to sandstone, clay-beds, or conglomerate, or from either one to the other, and especially where there is also a striking change in the organic remains, indicates a transition in the era from one set of circumstances to another,—it may be a change from one level to another in the continents, a submergence or emergence, or some other kind of catastrophe. All such transitions mark great events in the history of the continent, and thus divide the era into periods, and periods into epochs, and epochs, it may be, into sub-epochs. Hence,—

Fifthly. Through the ages each continent had its special history; and the periods and epochs in that history are indicated by changes or transitions in the rock-formations and their fossils.

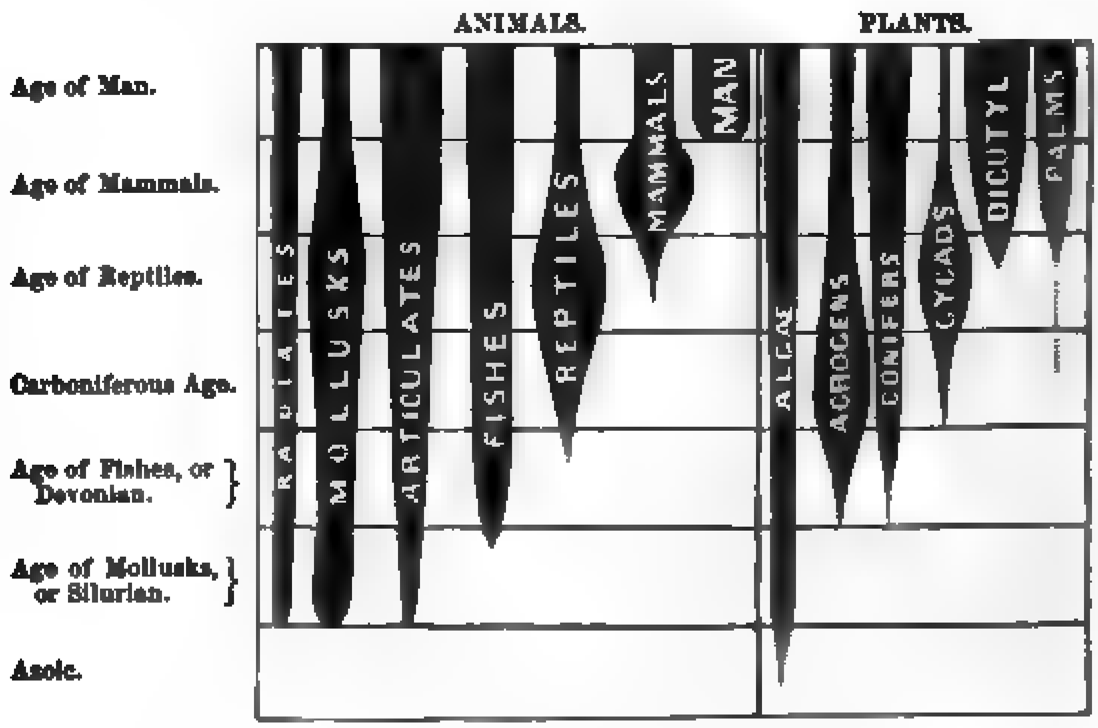
It is greatly to the assistance of research that some of the revolutions of the globe have probably been nearly or quite universal. The one preceding the Mammalian age appears to be an example; although, even with regard to this, further investigation is required before its actual universality can be regarded as established. But the periods and epochs of America and Europe are not in general the same in their limits. A near cotemporaneity in rocks may be proved, but not in the transitions from one rock to another. For example, the Devonian age has a very different series of periods and epochs in North America from what it has in Europe, and there is even considerable diversity between the epochs of New York and the Atlantic slope, and those of the Mississippi valley. The Carboniferous, Reptilian, and Mammalian ages also have their American epochs and their European, differing from one another; and the differences between the continents increase as we come down to more modern times. There are Tertiary and Cretaceous rocks in America as well as Europe, but there is little reason for the assumption that

the transitions from one set of Tertiary or Cretaceous strata to another were, in the two, cotemporaneous. The point should be proved, not assumed. We add, therefore,—

Sixthly. It is an important object in geology to ascertain as nearly as possible the parallelism between the periods and epochs marked off on each continent, and study out the precise *equivalents* of the rocks, each for each, that all the special histories may read as parts of one general history, and thus contribute to the perfection of one geological system.

Progress of life as the basis of the subdivision into geological ages.—The general principles in the progress of life upon which the ages are based are shown in the annexed table.*

Fig. 133.



The horizontal bands represent the ages, in succession; the vertical correspond to different groups of animals and plants.

The Radiates begin with the Lower Silurian, and continue till now, rather increasing throughout the ages.

The Mollusks have their beginning at the same time, and continue increasing to the age of Reptiles; they then pass their maximum (as indicated in the figure) and decline.

* The system of ages is essentially the same with that proposed by Professor Agassiz,—the only difference consisting in calling the Silurian the age of Mollusks, instead of considering both the Silurian and Devonian the age of Fishes.

The Articulates, as the table shows, commence in the Silurian (as Crustaceans and Worms), and continue expanding in numbers and grade to the present time.

Fishes begin in the Silurian, are very abundant in the Devonian, and continue on, becoming increasingly diversified to the last, without much rise in grade.

Reptiles begin in the top of the Devonian, and reach their maximum in the Reptilian age.

Mammals begin in the Reptilian age, and have their maximum in the Mammalian age.

As to Plants, Sea-weeds (or *Algæ*) are the earliest of the globe, probably preceding animal life. The Acrogens begin in the Devonian, or earlier, and have their greatest expansion in the age of Coal-Plants, where they occur with abundant Conifers. Cycads begin in the Carboniferous, and have their greatest expansion in the Reptilian age. Dicotyledons begin in the closing period of the Reptilian age, and expand, along with Palms, through the age of Mammals.

The Silurian is eminently the age of Mollusks; for this is the highest branch of the animal kingdom which is represented at that time in all its grand subdivisions. Brachiopods, Conchifers, Gasteropods, Pteropods, Cephalopods, begin in the Lower Silurian, and the Molluscan type is thus unfolded at the outset, while the Articulates are represented by only the inferior marine divisions, and the Radiates, besides being an inferior type, are present only in the lower tribes of its three classes. The age is eminently, therefore, the age of Mollusks. Any fishes discovered in the Silurian would foreshadow, in the manner explained, the age of Fishes, as the Reptiles of the Carboniferous age foreshadowed the Reptilian age, and the Mammals of the age of Reptiles the Mammalian age.

In the Devonian age, the Fishes, the lowest of Vertebrates, are the dominant type. The Reptilian age is still more eminently an age of Reptiles, and the Mammalian age an age of Mammals, as is shown beyond in the survey of these ages.

On botanical data, the ages would be—*first*, the age of *Sea-weeds*, covering the ages of Mollusks and Fishes; *second*, the age of *Coal-Plants* or *Acrogens*, or the Carboniferous age; *third*, the age of *Cycads*, corresponding to the age of Reptiles; and, *fourth*, the age of *Palms* and *Dicotyledons*, corresponding to the Mammalian age. The only addition to the preceding divisions based on the animal tribes which is thence suggested by the vegetable kingdom is the *Carboniferous*. In the zoological series this might be called the age of *Amphibians*, as it is characterized prominently by the amphibian division of Reptiles.

The ages recognized are, then, *Age of Mollusks*, or *Silurian; Age of Fishes*, or *Devonian; Carboniferous Age; Age of Reptiles; Age of Mammals; Age of Man.*

Preceding these, there is the *Azoic* era,—the name being derived from the Greek α and ζωη, *life*, and signifying the absence of life. The Azoic rocks are mostly crystalline.

The Silurian, Devonian, and Carboniferous ages naturally stand somewhat apart from the following in the peculiar ancient forms of the great portion of their living tribes, and to the whole collectively the term Palæozoic era is appropriately applied,—the word "palæozoic" being from the Greek παλαιος, *ancient*, and ζωον. The following age, or age of Reptiles, is correspondingly termed the Mesozoic, from μεσος, *middle*, and ζωον, it being the *mediæval* era in geological history. The Mammalian age is termed the Cenozoic, from καινος, *recent*, and ζωον. (The words *Eocene*, *Miocene*, etc., subdivisions of the age, are in part from the same root.)

The subdivisions of geological time are, then,—

I. Azoic Time or Age.

II. Palæozoic Time.

1. The Age of Mollusks, or Silurian.
2. The Age of Fishes, or Devonian.
3. The Age of Coal-Plants, or Carboniferous.

III. Mesozoic Time.

4. The Age of Reptiles.

IV. Cenozoic Time.

5. The Age of Mammals.

V. Era of Mind.

6. The Age of Man.

Subdivisions into Periods and Epochs.—The subdivisions under the ages, the periods and epochs, vary, as has been said, in different countries. The following table (fig. 134) presents a general view of those of eastern North America, as far as the Palæozoic is concerned,—the Silurian, Devonian, and Carboniferous being well represented on the North American continent. The rest of the series is from European geology, in which the later ages are far better represented than in America. In this manual, American geology is in general first considered, and afterwards such further illustrations are drawn from other continents as are necessary for comprehensive views and generalizations. Where America is deficient in its records, the European are taken as the standard.

The names of the periods and epochs for the Palæozoic of America are the same that have been applied to the rocks by the New York geologists.

Fig. 134.

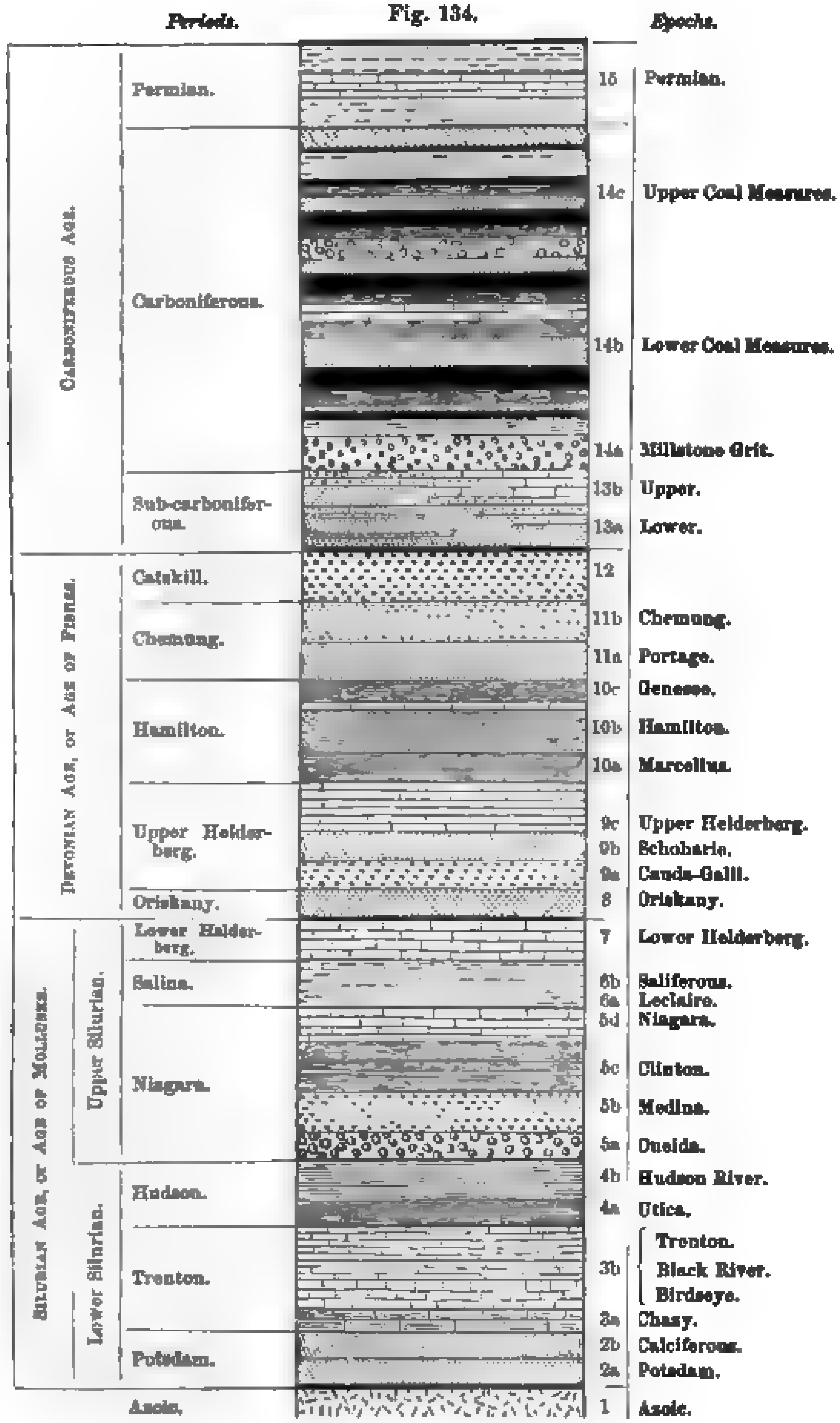
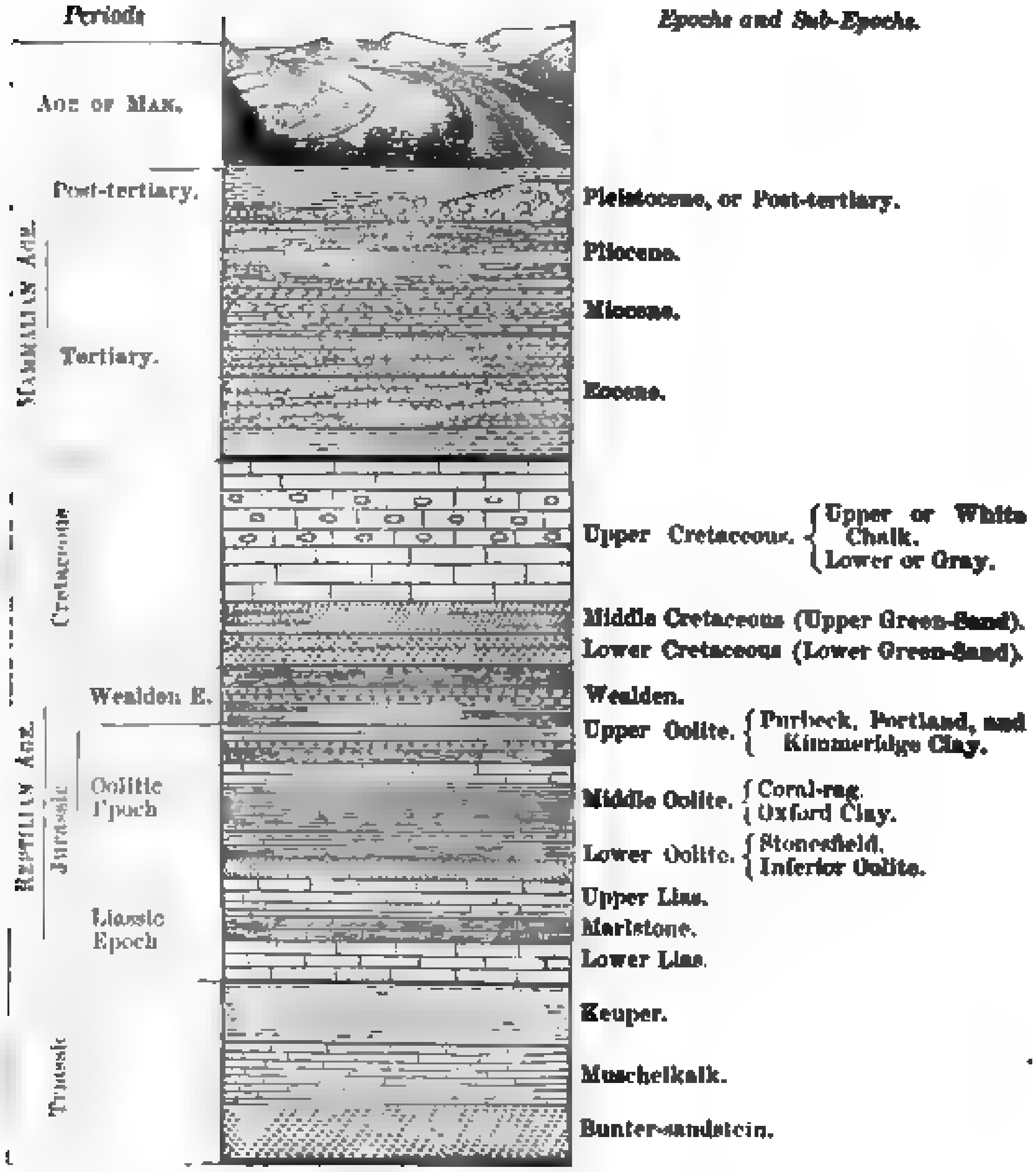

Periods.
Epochs.
Carboniferous Age.
Permian.
Carboniferous.
Sub-carboniferous.
15 Permian.
14c Upper Coal Measures.
14b Lower Coal Measures.
14a Millstone Grit.
13b Upper.
13a Lower.
Devonian Age, or Age of Fishes.
Catskill.
Chemung.
Hamilton.
Upper Helderberg.
Oriskany.
12
11b Chemung.
11a Portage.
10c Genesee.
10b Hamilton.
10a Marcellus.
9c Upper Helderberg.
9b Schoharie.
9a Cauda-Galli.
8 Oriskany.
Silurian Age, or Age of Mollusks.
Upper Silurian.
Lower Helderberg.
Salina.
Niagara.
Lower Silurian.
Hudson.
Trenton.
Potsdam.
7 Lower Helderberg.
6b Saliferous.
6a Leclaire.
5d Niagara.
5c Clinton.
5b Medina.
5a Oneida.
4b Hudson River.
4a Utica.
3b Trenton. Black River. Birdseye.
3a Chazy.
2b Calciferous.
2a Potsdam.
Azoic.
1 Azoic.

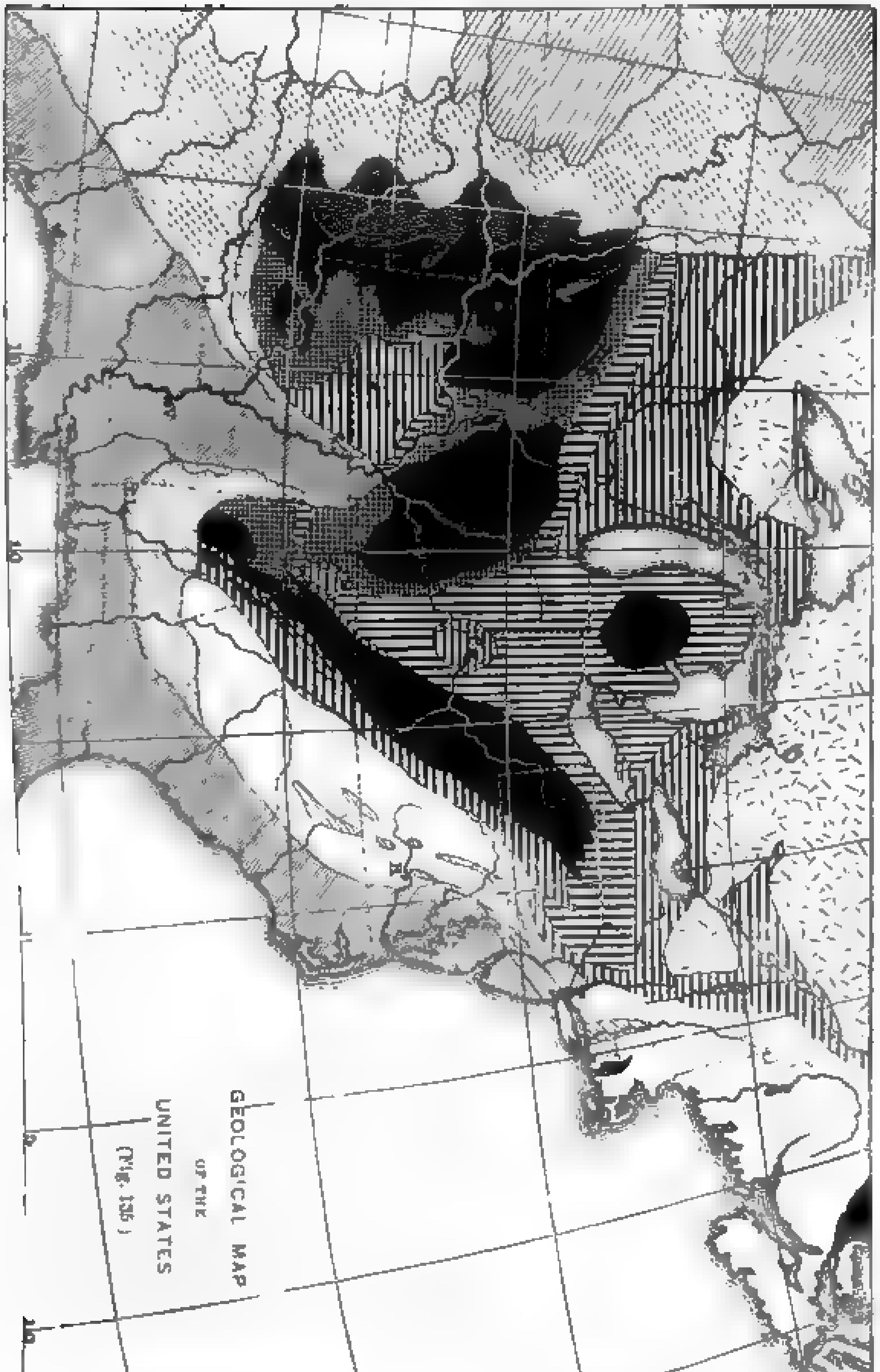
Fig. 134 (*continued*).



In the figures and maps introduced beyond, the numbers are used as in the above tables: 1 standing for the Azoic; 2 for the rocks of the Potsdam period, 2 *a* for the Potsdam epoch, 2 *b* for the Calciferous sand-rock; 3 for rocks of the Trenton period, 3 *a*, 3 *b*, for the epochs of this period; and so on.

The following map of the United States east of the Rocky Mountains exhibits the geographical distribution of the rocks of the several ages,—that is, the regions over which they are severally the *surface-rocks*.

The *Silurian* is distinguished by heavy horizontal lining; and the dotted line over the Silurian area divides the Upper Silurian (*u*) from the Lower Silurian (*l*).


GEOLOGICAL MAP
OF THE
UNITED STATES
(Fig. 135.)

The *Devonian*, by heavy vertical lines.

The *Carboniferous*, by light cross-lines on a black ground, or by a black surface, or by dots on a black ground (the *first* the Sub-carboniferous, the *second* the Coal formation, the *third* the Permian).

The *Reptilian*, including the Triassic, Jurassic, and Cretaceous, by lines sloping from the right to the left (/), the Cretaceous being distinguished by having the lines broken.

The *Tertiary*, by lines sloping from the left to the right (\ ).

The *Azoic*, by irregular line-dottings.

The surface without markings is occupied by rocks of undetermined age, that on the east mostly crystalline.

I. AZOIC TIME OR AGE.

Reality of the Age.—The Azoic age is the age in the earth's history preceding the appearance of animal life. The fact of the existence of the globe at one time in a state of universal fusion is placed beyond reasonable doubt. And whatever events occurred upon the globe from the era of the elevated temperature necessary to fusion, down to the time when the climate and waters had become fitted for animal life, are events in the *Azoic* age. The age must, therefore, stand as the first in geological history, whether science can point out unquestionably the rocks of that age or not.

The fossils of true Palæozoic and Mesozoic rocks have often been obliterated by the crystallization of these rocks; and, as the oldest rocks of the globe are nearly all crystallized, the question may always arise with respect to any particular one of them, whether it may not *once* have been filled with fossils. After having reached what was thought to be the lowest fossiliferous beds in Great Britain, fossils have been found in others inferior, carrying the Silurian down to a still lower level by transferring to it what had been regarded as Azoic. Such changes are part of the progress of the science, and cause little inconvenience to the system, provided the order of succession be rightly given.

Stratigraphical limits in North America.—The Azoic rocks in North America* at present include all that are older than the Potsdam sandstone of New York,—the first of the Silurian. This sandstone is spread out in nearly horizontal layers, conformable with the overlying Silurian beds, but rests on crystalline rocks, which are upturned at all angles and folded or crumpled on a scale of great

* The Azoic system of North America was first distinctly recognized in its true importance in the Report of Foster & Whitney on the Lake Superior region. The rocks inferior to the Silurian have been called by Murchison the *Bottom rocks*. They are part of the *primary* of the old geologists.

extent. These beds, thus crystallized and flexed or disturbed before the Potsdam sands were deposited, are the Azoic. The following sections illustrate this point. In each, the Azoic, numbered 1, in its usual disturbed condition, is overlaid nearly horizontally by the Silurian beds, 2 *a* being the Potsdam sandstone, 2 *b* the Calciferous sandrock, 3 the Trenton limestones, 4 *a* the Utica shale.

Fig. 136.

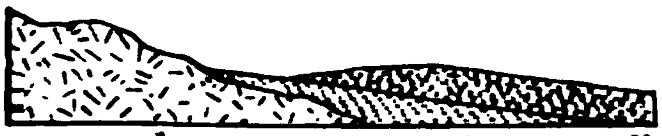


Fig. 137.

Fig. 138.

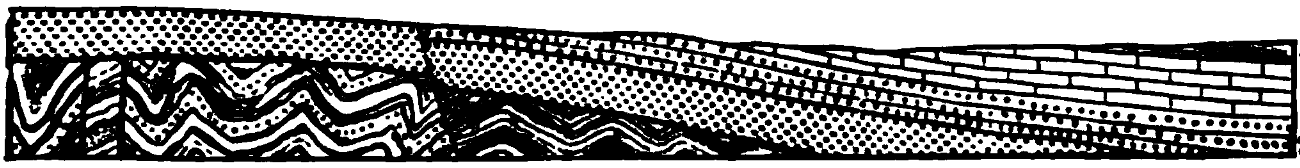


Fig. 136, by Emmons, from Essex co., N.Y.; 1 is hypersthene rock, or hyperite.—Fig. 137, by Owen, from Black River, south of Lake Superior; 1 is a granitic rock, 1 *a*, chloritic and ferruginous slates.—Fig. 138, by Logan, from the south side of the St. Lawrence in Canada, between Cascade Point and St. Louis Rapids; 1, gneiss.

Geographical distribution.—The Azoic rocks constitute the only universal formation. They cover the whole globe, and were the floor of the oceans and the rocks of all emerged land when animal life was first created. But subsequent operations over the sphere have buried the larger part of the ancient surface, and to a great extent worn away and worked up anew its material; so that the area of the old floor now exposed to view is small.

The areas of the earth's crust over which the Azoic rocks are now exposed are either,—

1. Those which have always remained uncovered.

2. Those which have been covered by later strata, but from which these superimposed beds have been simply washed away, without much disturbance.

3. Those once covered, like the last, but which, in the course of the upturnings of mountain-making, have been thrust upward among the displaced strata, and in this way have been brought out to the light.

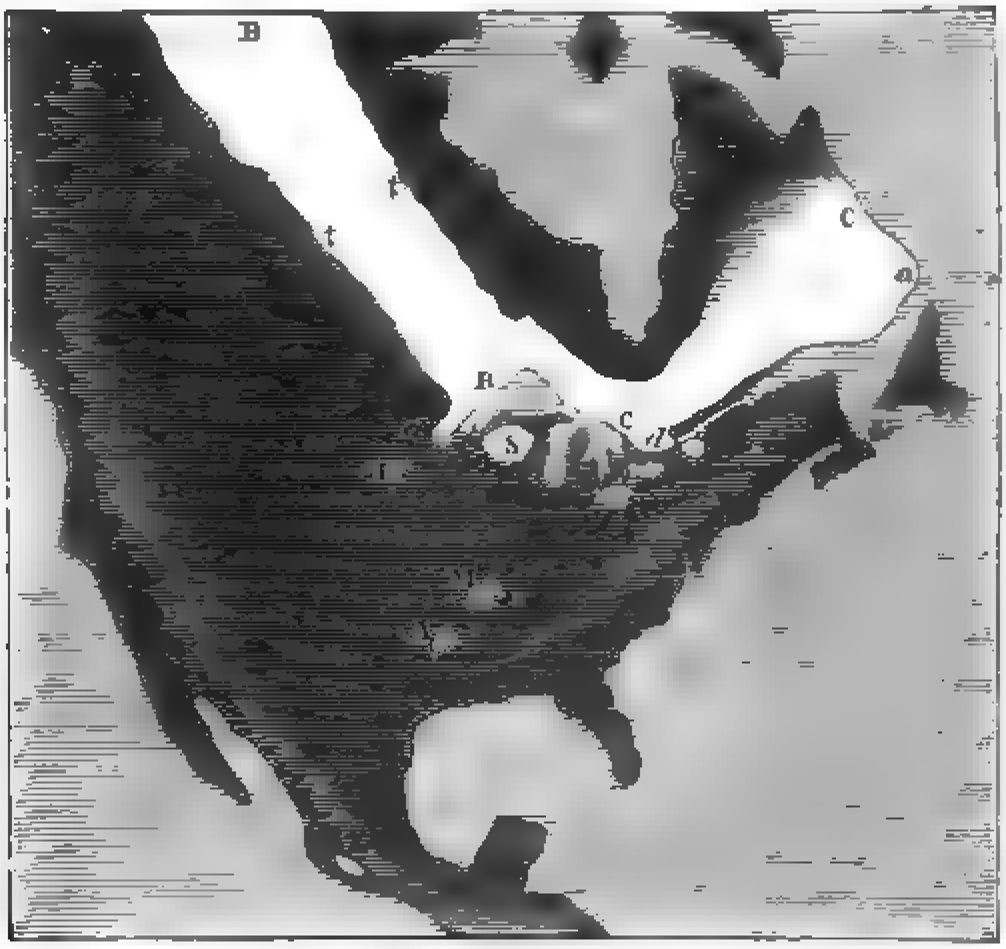
In cases like those of figures 136, 137, in which the Silurian rocks are spread in nearly horizontal layers over the borders of an area made up of tilted Azoic rocks, the Azoic area either has been always uncovered, or has become so from denudation; but in mountain-regions where the Silurian rocks have been folded up in the mountain-making, the Azoic below may have been brought

up to view in the same process. Moreover, the Azoic, if it had not undergone flexures before the Silurian beds were laid down, would partake of the Silurian flexures, or, in other words, be conformable to the Silurian strata. But if it had been flexed or tilted in some previous period of disturbance, then the Azoic would be unconformable to the Silurian, although both were finally upthrown together in the making of the mountains.

In the study of Azoic regions these points require special investigation.

The Azoic areas of North America of the first kind (and partially, it may be, of the *second*) are shown, as far as now ascertained, on the accompanying map of the Azoic continent. The Azoic lands on this

Fig. 139.



Azoic Map of North America.

chart are represented as the dry land of the era, while the rest of the continent is submerged. They are concluded to have been thus dry, because no marine beds cover them, while, on either border, marine beds (Silurian and later) commence and spread widely over the most of the continent. The outline of the continent and of the

great lakes enables the reader to perceive the relative positions of these Azoic lands. There may have been other areas along the Appalachians, and over the Rocky Mountain region, which future study will bring to light.

The Azoic regions laid down are—

1. Canada north of the St. Lawrence, reaching northeast from Lakes Huron and Superior to Labrador (C C), and the continuation northwest (B B) to the Arctic Ocean.

2. An isolated area in northern New York,—a peninsular prolongation, it may be considered, of the Canada region,—covering for the most part Essex, Clinton, Franklin, St. Lawrence, Hamilton. and Warren cos., and part of Saratoga, Fulton, Herkimer, Lewis, and Jefferson cos.

3. A similar area south of Lake Superior (S).

4. West of the Mississippi, a small area in Missouri, in which the famous Iron Mountains are situated; the Black Hills in Dakota, and the Laramie Range in Nebraska, as recently observed by Dr. Hayden; part of the Ozark Mountains in Arkansas.

In northern New Jersey there are Azoic gneiss, limestone, and other crystalline rocks containing great beds of the ore called Franklinite, analogous to the iron-ore beds of northern New York: the lowest Silurian beds cover them unconformably. Professors Rogers have described the occurrence of Azoic rocks in the Appalachians; but, although probably occurring in the range, the evidence is not yet conclusive that the rocks so designated antedate the Silurian. Professor Safford mentions rocks of the Azoic age in eastern Tennessee,—a part of the same mountains; but they are stated to be *conformable*, as far as yet investigated, to the Silurian.

The map of New York and Canada in the chapter on the Silurian shows more precisely the form of the New York Azoic and that north of the St. Lawrence. It represents also the Silurian and Devonian strata of the State as they become successively the surface-rocks on going from the Azoic southward. Adjoining the Azoic (numbered 1) is the earliest Silurian, No. 2, which outcrops where it is represented, but is supposed to underlie the strata numbered 3, 4, 5, etc. So No. 3 is the next formation which outcrops, while it probably underlies all the beds 4, 5, etc. The Azoic is thus the basement, and each successive stratum was a new deposit over it in the seas that bordered at the time the Azoic dry land.

In Europe the Azoic system has been distinctly recognized in Norway and Sweden and in Bohemia underlying the Silurian unconformably. The great iron-regions of Sweden are probably of this age. In geological maps of other parts of the world (and those of Europe and America are not always excepted) it is

common to color the regions covered by crystalline rocks all alike, without reference to their differences of age. Thus the metamorphic rocks of various ages are confounded, as they are also in the unfortunate name they sometimes bear, of *hypogene* rocks.

Kinds of rocks.—The rocks are mostly of the metamorphic series, related to granite, gneiss, syenite, and the like. But they embrace only the most ancient of these rocks; for the granites and schists of New England, of Cornwall, the Alps, and many other regions, belong to later ages.

Besides true *granite* and *gneiss*, there are *diorite*,—a rock consisting of feldspar (albite) and hornblende without quartz (§ 84); also extensive ranges of coarse granite-like rocks of grayish and reddish-brown colors, composed mainly of crystallized labradorite or a related feldspar (§ 55), or of this feldspar with the addition of the brownish-black and bronzy foliated mineral hypersthene (§ 65), and constituting the rock called *hyperite;* also *chlorite schist*, while mica schist appears to be absent; also *serpentine*, *limestone* (or *statuary marble*), *granular quartz* (a hard sandstone), and in some places a hard *conglomerate;* also *magnetic* and *specular iron-ore* in immense beds.

There are, in addition, *porphyry* of green, brown, and reddish colors; a garnet-euphotide (eclogite) and a feldspar-euphotide (§ 85); soapstone (Rensselaerite) (§ 86, [4]); parophite rock and schist (§§ 67, 87); pyroxene rocks; ophiolites or verd-antique marble of different varieties (§ 86, [8]).

Part of the feldspar related to labradorite has the composition of andesine or vosgite; and oligoclase exists in the Swedish Azoic. The Labrador rock turns gray on weathering. Part of the hyperite contains ordinary hornblende instead of hypersthene, and some kinds mica or epidote. The hypersthene is in foliated pieces or crystals often a little bronze-like in lustre. Good localities for the opalescent labradorite are the streams of the Adirondack,—especially, says Professor Emmons, the beaches of East River; also Avalanche Lake, near the foot of the great slide from Mount McMartin.

The potstone or soapstone called *Rensselaerite* covers considerable areas in the towns of Fowler, Canton, Edwards, Hermon, etc., St. Lawrence co., and at Grenville, in Canada, and is cut into slabs for tables, chimney-pieces, furnace-linings, or made into inkstands. The *parophite* or aluminous potstone of Diana, Lewis co., N.Y. (§ 87), is also used for inkstands, etc.

Beautiful red and green porphyry and a buhrstone are found at Grenville, Canada.

As crystalline rocks have been formed in various ages,—those of New England, for example, long after those of the Azoic,—it is possible that some Azoic rocks have undergone a second or third alteration subsequent to the original one in the Azoic age. It may be difficult, in fact, to say which of the rocks retain their original

composition. There is, however, no reason to suspect any fundamental changes in the granitic or hornblendic rocks or schists. But the potstones, both magnesian and aluminous, are probably of later origin. The Rensselaerite has been observed under the crystalline form of pyroxene, showing that in part, at least, it has been made out of pyroxene; and the aluminous species exists under the crystalline form of nepheline, giving unequivocal proof that it has been made out of pre-existing nepheline crystals, like the gieseckite of Greenland, which it resembles in aspect and composition. The rocks are probably, therefore, the result of the alteration of different minerals or rocks after the first Azoic crystallization. If this be true, they may not be actually Azoic rocks: they may belong to the same age with the metamorphic rocks of New England, or to some other period. By one interested in bringing the events of geological history into their true chronological relations,—the real end in geological studies,—this will be regarded as an important question.

Other evidences of alteration since the original crystallization in northern New York have been observed,—such as the rounded quartz crystals of Gouverneur, and the soft spinels of St. Lawrence co., called houghite. Even the serpentine of the same region may come into this category.

Minerals of the Azoic rocks.—Besides the constituent minerals mentioned,—viz., quartz, feldspar of different species, hornblende, pyroxene, epidote, mica, talc, garnet,—there are also the following common species: tourmaline, scapolite, wollastonite, sphene, rutile, graphite, the mica called phlogopite (§ 56), apatite, chondrodite, spinel, zircon, corundum,—each of which occurs at times in the crystalline limestone or its vicinity. Mica is found in Grenville, Canada, in plates between one and two feet square. In addition to these, there are a number of rare ores of yttrium, cerium, and columbium among the Swedish Azoic rocks.

No gold has thus far been found in the Azoic. Andalusite, kyanite, and staurotide are also among the common minerals of crystalline schists not detected in the Azoic.

Characteristics of the Azoic rocks.—1. The Azoic rocks are nearly all crystalline rocks. A few sandstones, slates, and conglomerates are the only exceptions; and these are excessively hard rocks.

2. The crystalline rocks are remarkable for the small amount of silica they contain (a fact noticed by T. S. Hunt). This is seen in the absence of quartz from many of the rocks (the diorite, Labrador rock, hyperite), and the abundance of feldspars, like labradorite, that have a low proportion of silica.

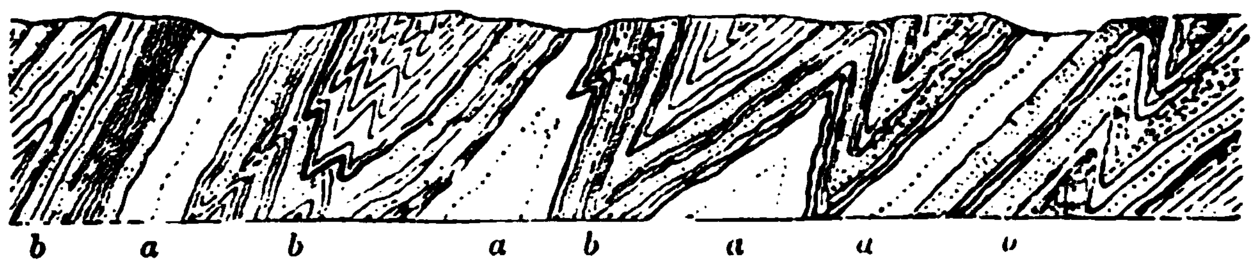
3. The prevalence of iron is another characteristic (remarked by J. D. Whitney). This is seen in the abundance of the minerals (silicates) containing iron, as hornblende, hypersthene, chlorite, garnet; also the reddish color of much of the feldspar; also the beds of iron-ore, which exceed in extent those of any other age.

4. There are none of the simple silicates of alumina.

Arrangement of the rocks.—Although the Azoic rocks are mostly crystalline, they follow one another in various alternations, like the sedimentary beds of later date. In the sections which have been given, there are alternations of granite, gneiss, schists, limestone, etc.; and the dip and strike may be studied in the same manner as in the case of any tilted sandstones or shales. The following sections represent other examples; and in them there are beds of iron-ore, one hundred feet and upwards in thickness, which are banded with siliceous layers and chloritic schist, showing thereby a distinctly stratified character. Where most flexed or folded, there is still a distinction of layers; and it is owing to this fact that the rocks may be described as folded; for folds can be identified only where the rocks are in sheets. This grand fact is, then, evident,—that the Azoic rocks are in layers, as much as the rocks of any later age.

The following section by Logan (real in its general truths, although partly ideal) exhibits well this fact. It presents to view a stratum of (*a*) white

Fig. 140.



granular or crystalline limestone, many times folded, and interstratified with gneiss and quartz rock (*b*); and over the same region (Grenville and adjacent country, Canada) the limestone has been traced in linear and curving bands corresponding to a series of folds.

The following sections contain iron-ore beds among the alternations. In

Fig. 141.

Fig. 142.

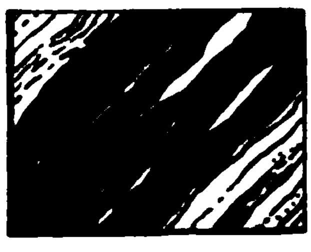
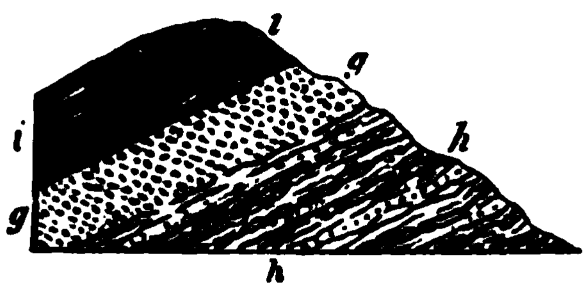


Fig. 143.

fig. 141 (from the Michigan region, Foster & Whitney) the iron-ore, in extensive beds (*i*, *i*), occurs between chloritic schist (*a*, *a*) and diorite (*b*); and the iron-

ore in *i* is banded with jasper. In figs. 142 and 143 (Essex co., N.Y., Emmons) the iron-ore, in beds several yards wide, is associated with gneiss and quartz rock, and is interlaminated with quartz, the whole dipping together in a common direction, like beds of sandstone, shale, and iron-ore in many regions of sedimentary rocks.

Fig. 144.



In fig. 144 (Penokie Range, south of Lake Superior, C. Whittlesey) *h* is hornblende rock and slaty quartz; *g*, quartzite, 30 feet thick; *i*, a bed of iron-ore, 25 to 50 feet thick.

In another section, by C. Whittlesey (described in Foster & Whitney's Report), taken at the falls of the Menomonee, there are alternations of gneiss, hornblende, and quartz rock with talcose and chloritic schists, quartzite, and granular limestone, and between the limestone layers there is a layer of *iron-ore*,—showing again that the iron-ore is in beds conformable with the schists. The beds, however, may not have great lateral extent; for the iron may be local in bands, or imbedded in other kinds of rocks.

In the Missouri region, at Pilot Knob, the ore-strata (says J. D. Whitney) consist of a series of quartzose beds of great thickness, passing gradually into specular iron, which frequently forms bands of nearly pure ore, alternating with bands of quartz more or less mixed with the iron. The ore, moreover, is often thin-laminated.

At the Adirondack mines, in Essex co., N.Y., one bed, according to Emmons, is 150 feet thick, and another exceeds 700 feet. In the Michigan region they are on the same great scale. In Missouri, one of the "iron mountains"—the Pilot Knob—is 581 feet high, and the other 228 feet; and huge displaced masses, some ten and twenty tons' weight, lie over the surface. The iron-ore in each of these regions is partly magnetic and partly specular ore, or hematite,—that of Lake Superior and Missouri mostly the latter, and that of New York mainly the former.

In Canada, at Bay St. Paul's, there is a bed of titanic iron 90 feet wide, exposed for 200 or 300 feet, occurring in syenite with rutile or oxyd of titanium. The ore does not differ from ordinary specular iron in appearance, but the powder is not red. In Sweden and Norway the iron-ores are interstratified in the same manner with crystalline rocks,—mainly gneiss, hornblende rocks, talcose and chloritic schists, argillaceous schists, quartzite, and granular limestone, with which they are more or less laminated. At Dannemora, the stratum containing iron is 600 feet in width; and it occurs with granular limestone, talcose and chloritic schists, and gneiss. At Utö, Sweden, red, jaspery quartz bands the ore, in the same way as in Michigan; the ore—the specular mixed with the magnetic—occurs in mica schist and quartzite, in an irregularly-shaped mass, about 120 feet in its widest part. At Gellivara there is an iron mountain three or four miles long and one and a half wide, consisting mostly of magnetic iron-ore, with some specular ore. In each of these regions the beds dip with the enclosing rock,—showing that all have had a common history.

In the annexed sections (St. Lawrence co., N.Y., Emmons), granular lime-

stone is represented in connection with granite and other rocks. In fig. 145, *l* is limestone, without any appearance of stratification; and the containing rock is granite. In fig. 146, *a a* are gneiss, *b* steatite, *l* unstratified limestone.

Fig. 145.

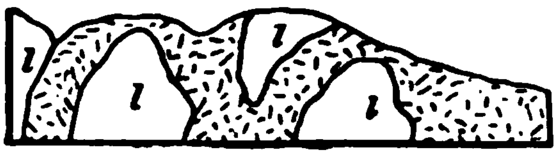


Fig. 146.

Although *a* and *b* are not evenly stratified, yet they are sufficiently so to show that the limestone, while it has lost its division into layers in the crystallizing process, is probably a conformable stratum.

The *order of stratification* among the Azoic rocks is as various as among the rocks of other ages. As sandstones, shales, argillaceous sandstones, conglomerates, follow one another in any succession, so granite or gneiss may lie between layers of slate or schist, and quartz rock may have any place in the series. It is common, however, to find the different hornblendic rocks associated together; and both these and the chloritic often abound in the iron-regions, since hornblende and chlorite are ferriferous minerals. Again, chloritic schists are apt to accompany serpentine; since chlorite is a hydrous magnesian species.

Again, as we recede from a granite region we sometimes find the rocks less and less perfectly crystalline, passing from the granite to the gneissoid, from these to the schistose, and last to those least crystalline and containing water, as talcose and chloritic schist and serpentine. But there are numberless exceptions to such an order.

The Azoic rocks of Canada are divided by Logan into the *Laurentian*,—including the great part of the system, and embracing all the regions to which we have above particularly alluded,—and the *Huronian*, comprising a narrow band on the borders of Lake Superior and Lake Huron. The Huronian are thus separated because they have been found to rest unconformably upon the Laurentian. They consist of siliceous slates, schists, quartzite, conglomerates, and limestones. The conglomerates contain pebbles and boulders (some a foot in diameter), which are derived in part from gneiss or syenite of the subjacent Azoic, and thus show their later origin. Others contain pebbles of jasper and quartz very firmly cemented. The sandstones are described also as bearing ripple-marks. These rocks occur on Lake Temiscaming and on the north shore of Lake Huron. No similar rocks have been observed to the eastward of these districts, over all Canada to Labrador; and if ever there, they have been removed by denudation. The Huronian rocks are intersected by numerous dikes of trap, and interstratified and overlaid by the same rock. The total thickness of the formation, according to Logan, is over twelve thousand feet. The iron-

ore region of Marquette, in Michigan, has been referred to the Huronian. Should these Huronian rocks be found hereafter to contain any fossils, they would form the first member of the Silurian.

According to Hunt, no talcose or chloritic schists occur among the Laurentian rocks.

Original condition of the Azoic beds.—The alternations of argillaceous, chloritic, and other schists with quartzites, limestone, gneiss, and the other Azoic rocks, prove that all were once sedimentary beds,—beds formed by the action of moving water, like the sandstones, argillaceous beds, and limestones of later times. They have no resemblance to lavas or igneous ejections. The schists graduate into true slates, and the quartzites into unmistakable sandstones and conglomerates; so that there is direct proof in the gradations as well as the arrangement in alternating layers that all the schistose and siliceous rocks are parts of one series of sedimentary beds which by some process have been hardened and crystallized. Moreover, from the gneiss there is as direct a passage to the gneissoid granite, and thence to true granite and syenite; so that even the most highly crystalline rocks cannot, as a general thing, if at all, be separated from this series. These Azoic rocks, therefore, are made out of the ruins of older Azoic,—that is, of the sands, clays, and stones gathered and deposited by the ocean as it washed over the earliest-formed crust of the globe. Whenever the ocean took its place upon the cooling globe, the conflict began, and sedimentary beds were the result; and the *original crust* is now so disguised amid these later crystallized deposits, which are here called Azoic, or is so buried beneath them, that geology can hardly expect to identify any portion of it. The loose material transported by the currents and waves was piled into layers, as subsequently in the Silurian, Devonian, and Carboniferous ages, and vast accumulations were formed; for no one estimates the thickness of the recognized Azoic beds as below fifteen or twenty thousand feet. Limestone strata occurred among the alternations; and argillaceous iron-ores, like the beds of the Coal measures, though vastly more extensive, were a part of the formations in the deposits.

The beds, moreover, were spread out horizontally, or nearly so; for this is the usual condition with sediments and limestones when first accumulated. The original condition, then, of the Azoic rocks was the same as that of ordinary sediments,—in horizontal beds and strata.

Disturbances and Foldings.—But, from the sections and descriptions on the preceding pages, it is apparent that *horizontal*

Azoic rocks are now exceedingly uncommon. The whole series has been upturned and flexed, broken and displaced, until little, if any, of it remains as it was when accumulated.

This upturning, moreover, is not confined to small areas, nor has it been done in patchwork-style; for regions of vast extent have undergone in common a profound heaving and displacement. This community of action or history is evident in the fact that the rocks have nearly a common *strike* (§ 113) over wide regions,—the strike being at right angles, or nearly so, to the action of the force causing the uplift.

The strike in the New York, Canada, Michigan, and Lake Superior Azoic is generally from the northeastward to the southwestward, or nearly parallel to the course of the Appalachians and Green Mountains or the line of the present Atlantic coast.

In the New York region, according to Professor Emmons, the course of the line of limestone from Johnsburg to Port Henry, on Lake Champlain, is nearly *northeast;* that of another, along by Rossie (between Black Lake and Pitcairn, and from Theresa nearly to Lisbon and Madrid), *north-northeast;* another, parallel to this, extends from Antwerp to Fowler and Edwards. These outcrops of limestone follow the line of strike; for the strike of the gneiss is in general from southwest to northeast, or parallel to the general course of the highlands, and therefore of the uplifts. The *dip* varies from 10° to 90° either side of the perpendicular. The iron-ore beds have the same strike; for all together constitute one system.

In Canada, the limestone ranges of the township of Grenville have the course, according to Logan, between northeast and north-northeast, and mostly the latter. The strike of the gneiss and schists has the same general course. The Azoic near Lake Superior appears to have the same mean strike.

This uniformity of direction attests to a uniformity in the direction or action of the uplifting force, as above remarked. The strike of the Azoic rocks of Scandinavia is also to the northeastward, with no greater variations than occur in the American Azoic; and this common course there, whether connected or not with that on the opposite side of the Atlantic, indicates some vast comprehensive agency as the origin of the disturbance.

The beds were laid down as sediments over immense continental areas; and then followed a period of uplift, when the horizontal layers were pressed into folds and displaced on the grand scale explained. Many such periods of uplift may have previously occurred. But it is evident that uplifting and disturbance were not the prevailing condition of Azoic times, any more than they were of later ages. This is proved by the conformability of the various Azoic beds to one another in this system of foldings. An age of comparative quiet, allowing of vast accumulations of horizontal strata, must have preceded the epochs of revolution.

Evidences of different epochs of revolution—that is, of uplift—may hereafter be detected in the Azoic; but thus far no definite progress has been made towards this end, excepting in the separation of the Huronian proposed by Logan.

Alterations: Solidification and crystallization.—Besides the universal displacements, there was an almost universal crystallization of the old sedimentary beds and limestones; and now, in place of the sands and clays and earthy limestone layers, the rocks are crystallized into granite, gneiss, syenite, granular limestone, etc., by the solidifying process, and thus have lost almost every trace of their original sedimentary aspect. The once massive and earthy limestones now contain in many places crystals of mica, scapolite, apatite, spinel, etc., in place of their old impurities, and the limestone itself is a white or variegated architectural marble. The argillaceous iron-ore has become the bright specular and magnetic ores, and it is banded by, or alternates with, schist and quartz, etc., which were once accompanying clay and sand layers.

Granite, syenite, and hyperite, although they present no lines of stratification or foliation, are embraced among the metamorphic rocks as an actual part of the series; for the slight difference of structure between them and gneiss is no evidence of difference of origin. Whatever crystals they contain besides their own crystalline grains,—as of pyroxene, garnet, sphene, wollastonite, hornblende, feldspar,—all were due to the same system of alteration.

The upturning may have brought up also the granites, syenites, and other rocks of a previous metamorphic period, or some of the nether granitic rocks belonging to the first-formed crust; but there is no means at present recognized for distinguishing them; and in many places the distinct alternation of the granite or syenite with the gneiss and schists proves beyond doubt their cotemporaneous origin, at the last great Azoic revolution, out of a common series of sedimentary strata. That this revolution preceded the Silurian age is known from the fact that the Silurian beds overlie them unconformably.

It is remarked on a preceding page that some of the Azoic rocks may have undergone a second or third alteration during the following ages, and that the magnesian and aluminous potstones and part of the serpentine and its associated minerals may be among these later products. The mind that has any adequate apprehension of the remoteness of that Azoic era will not question the probability of such changes, and is ready to wonder rather that the evidences of subsequent alterations are not more extensive and obvious.

Life of the Azoic Age.—The term "azoic," as here used, implies absence of life, but not necessarily of the lowest grades.

The reasons in favor of the existence of life of some kind are—

1. The formation of limestone strata in the Azoic age like those

of the Silurian, in connection with the fact that Silurian and later limestones are known to be mainly made from organic relics.

2. The occurrence of graphite in the limestone and other strata, —graphite being known to be a common result of the exposure of mineral coal or charcoal to a high heat, and, in certain rocks of Rhode Island and Massachusetts, having undoubtedly been made from vegetable remains.

3. The occurrence of anthracite in small pieces in the iron-bearing rocks of Arendal, Norway, which rocks are probably Azoic in age.

Against this organic origin it may be urged that the limestones and graphite may have been of chemical origin; and in the earlier age of the globe, when there existed a heat too great for animal life, the occurrence of such chemical formations is not improbable: yet the argument still leaves it an open question.

Supposing the existence of life of some kind, it is more likely to have been *vegetable* than animal.

1. In the progressing refrigeration of the globe, a temperature fit for vegetable life would have been reached before that which animal life could sustain. If there is any exception to this, it is to be found only among the lowest species of animal life; and there is as yet no evidence that such exceptions exist.

2. The graphite and anthracite indicate vegetable life, if any at all.

3. There are among the Azoic rocks, slates, sandstones, quartzites, and conglomerates which are not more altered than some Silurian rocks containing fossils; and, had Mollusks and Crinoids existed, shells and Encrinites should be found in the beds. Moreover, the great beds of iron-ore rarely contain a trace of phosphates; and this is some indication that there was little or no animal life.

4. The Silurian formation commences with the same genera and partly with the same species of animal life in different parts of Europe and America,—indicating that the actual bottom of the series of animal life had been reached alike in both countries.

5. Again, in America a period of folding and crystallization appears to have terminated the Azoic age, making a fitting close to the era of the earth's primal inorganic history. The latter part of this long time of revolution (whose centuries may have been counted by scores) was the epoch of the unfossiliferous Huronian beds,—since these terminate the Azoic, according to Logan. They indicate, as far as studied, no existing animal races.

6. It is possible that vegetable life may make strata of lime-

stone. There are coral-secreting plants as well as animals; and such plants are called Corallines. There are also microscopic infusorial plants; and those secreting silica—the siliceous infusoria (Diatoms)—are known in later times to have made extensive beds of rocks. Limestone beds have been made from the microscopic Rhizopods; for chalk is largely due to their growth and accumulation. And these Rhizopods, although animal, are extremely low in the scale,—little above the spores of sea-weeds: so that, if existing then, they simply foreshadowed the future animal kingdom.

Whenever the earliest plant, however minute, was created, then the grand idea of life first had expression, and a new line of progress in the earth's history was announced.

Relations of the North American Azoic to the continent.—The map, fig. 139, cannot be examined without perceiving at once the following striking facts:—

That the great Azoic area of the continent has (1) its longer leg, *B B*, parallel approximately to the Rocky Mountains and Pacific; and (2) its shorter, *C C*, parallel to the Appalachian Range and the Atlantic; that—

(3) The peninsula of Florida is nearly in the course of the Pacific branch, *B B*; and (4) the Missouri and Arkansas Azoic regions (*M A*) are nearly in the course of the Atlantic branch, *C C*.

(5.) That the northwest side of Lake Superior and the Azoic of the Black Hills lie in the same line.

Such are some of the structure-lines of the continent in this its early or Azoic state. They are features that were never afterwards effaced: instead of this, they were manifested in every new step in the progress of the continent.

[From this point the progress of the life of the globe is a prominent part of geological history. A brief review of the system of life is therefore here introduced, together with some of the details respecting those of the subdivisions that characterize the Silurian age.]

1. ANIMAL KINGDOM.

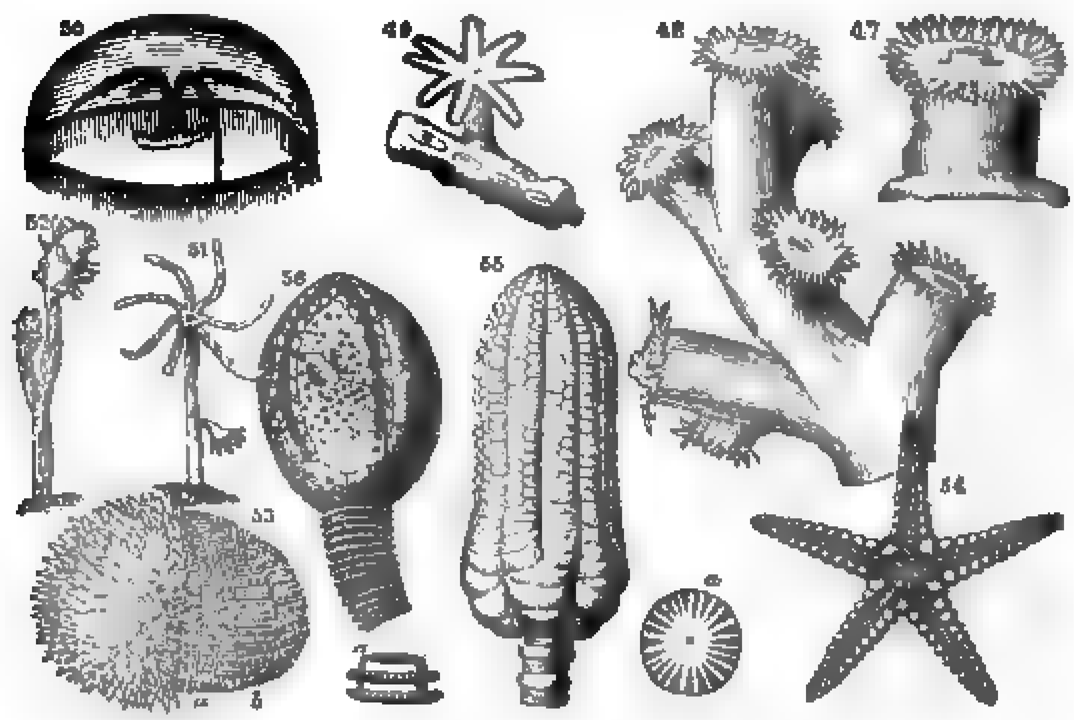
In the Animal Kingdom there are *four* SUB-KINGDOMS, based on four distinct types of structure, each having its system of subdivisions of several grades or ranks. These sub-kingdoms are as follow, beginning with the lowest:—

I. **Radiates.**—Having a *radiate* structure, like a flower or a star, internally as well as externally. The animals have a mouth and

stomach for eating and digestion, and hence they are widely diverse from plants.

The figs. 147 to 156 represent examples of Radiates: 147, an *Actinia*, or *Polyp;* 148, 149, living corals, the animals of which are polyps; 150, a *Medusa*, or *Acaleph*,—also called *Jelly-fish*,—showing well the internal as well as external radiate structure, as the animal is nearly transparent; 151, 152, polyp-like species of the class of Acalephs; 153, an *Echinus*, or *Sea-urchin*,—but not perfect, as the spines which cover the shell and give origin to the name *Echinus* are removed from half its surface to show the shell; 154, a *Star-fish;* 155, 156, *Crinoids*,—animals like an inverted Star-fish or Echinus,

Figs. 147–156.



RADIATES, figs. 147–156. 1. *Polyps:* Fig. 147, an Actinia; 148, a coral, Dendrophyllia; 149, a coral of the genus Gorgonia. 2. *Acalephs:* 150, a Medusa, genus Tiaropsis; 151, Hydra (× 8); 152, Syncoryna. 3. *Echinoderms:* 153, Echinus, the spines removed from half the surface (× ½); 154, Star-fish, Palmaster Niagarensis; 155, *Crinoid*, Encrinus liliiformis; 156, *Crinoid*, of the family of Cystids, Callocystites Jewettii.

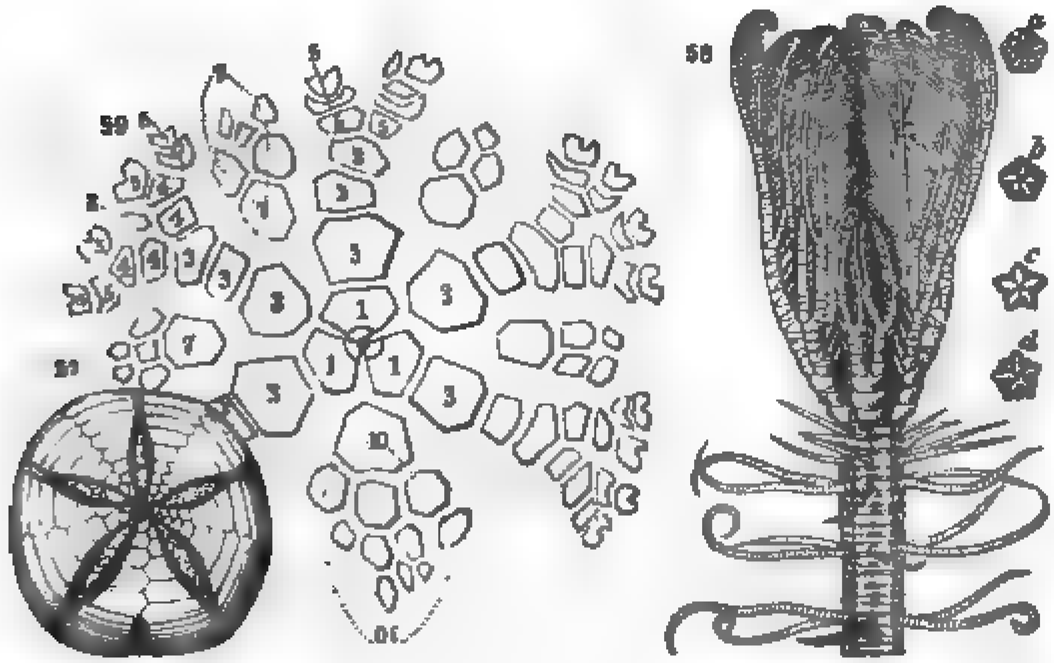
standing on a stem or pedicel, like a flower. Fig. 157 is the shell of another Sea-urchin; and fig. 158, another Crinoid. Figs. 523 to 535 are additional examples of Radiates.

The radiate feature exists not only in the external form, but also in the interior structure. The mouth, when furnished with calcareous jaws or mandibles, has a circle of five of them; and the nervous system, when distinct, is circular in arrangement.

II. **Mollusks.**—The structure essentially (1) a soft, fleshy bag,

containing the stomach and viscera, (2) without a radiate structure, and (3) without articulations. The animals of the Oyster and Snail are examples. In some kinds there are eyes and arms, but the arms or appendages are never jointed; and in this the species are distinct from *Articulates*.

Figs. 157–159.



RADIATES.—Fig. 157, an Echinus without its spines,—the Clypeus Hugi of the Oolite; 158, the living Pentacrinus Caput-Medusæ of the West Indies (× ⅙); *a*, *b*, *c*, *d*, outline of the stem of different species of Pentacrini; 159, plates composing the body of a Crinid, Actinocrinus longirostris *Hall*.

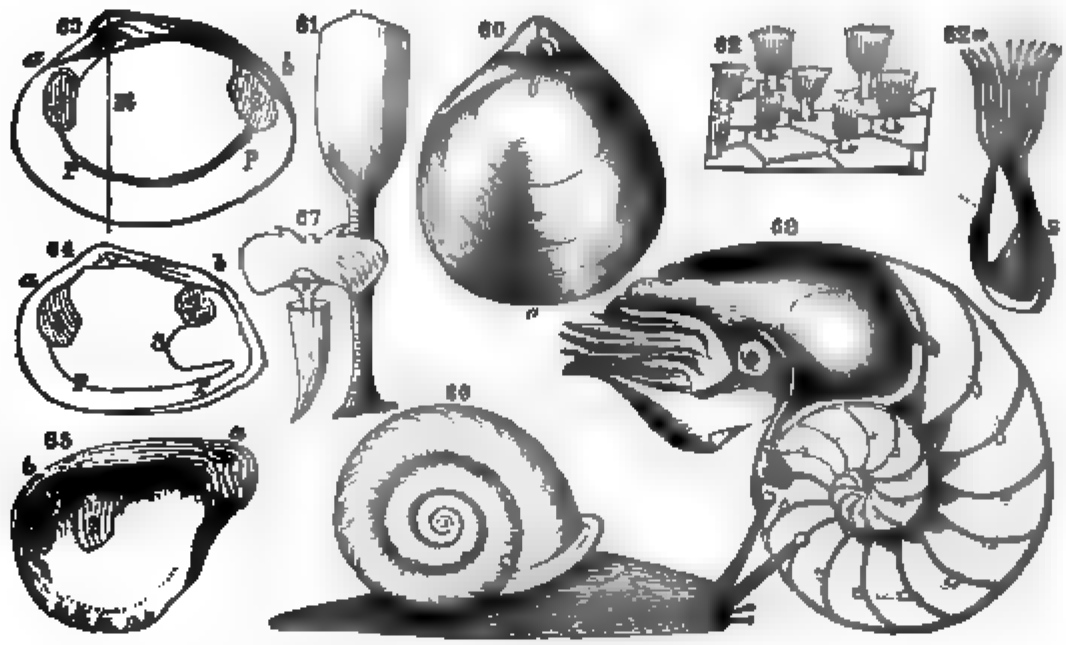
Figs. 160 to 168 represent some of the kinds of Mollusks. Figs. 160, 163, 164, 165, are shells of different species; 166, the shell of a snail, with its animal; 168, another shell, the *Nautilus*, with its animal; 162, a magnified view of a minute coral, with the living animals projecting from the cells, which, although apparently radiated like a polyp, are still Mollusks, because this radiation is only external, as is apparent in fig. 162 *a*, which represents one of the animals taken out of the cell and more magnified. Fig. 169 is another Mollusk,—a Cephalopod,—having some resemblance to the Radiates in the position of the arms, but none beyond this.

The name Mollusk is from the Latin *mollis*, *soft*. The shells are for the protection of the soft, fleshy bodies.

III. **Articulates.**—Consisting (1) of a series of joints or segments, and (2) having the viscera and nervous cord in the same general cavity, but (3) having no *internal* skeleton; as *Worms*, *Crustaceans*, *Insects*.

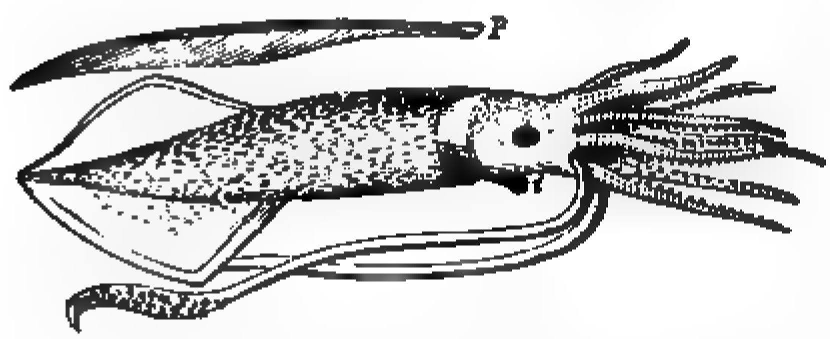
The articulations are made in the hardened skin, and not, as in Vertebrates, in internal bones; and the principal nervous cord

Figs. 160–168.



MOLLUSKS, figs. 160–168.—1. *Brachiopods:* 160, Terebratula impressa, of the Oolite; 161, Lingula, on its stem. 2. *Bryozoa:* 162 (× 8), 162 *a*, genus Eschara. 3. *Conchifers*, or *Common Bivalves:* 163, 164; 165, the Oyster. 4. *Gasteropods:* 166, Helix. 5. *Pteropods:* 167, genus Cleodora. 6. *Cephalopods:* 168, Nautilus (× ½).

Fig. 169.

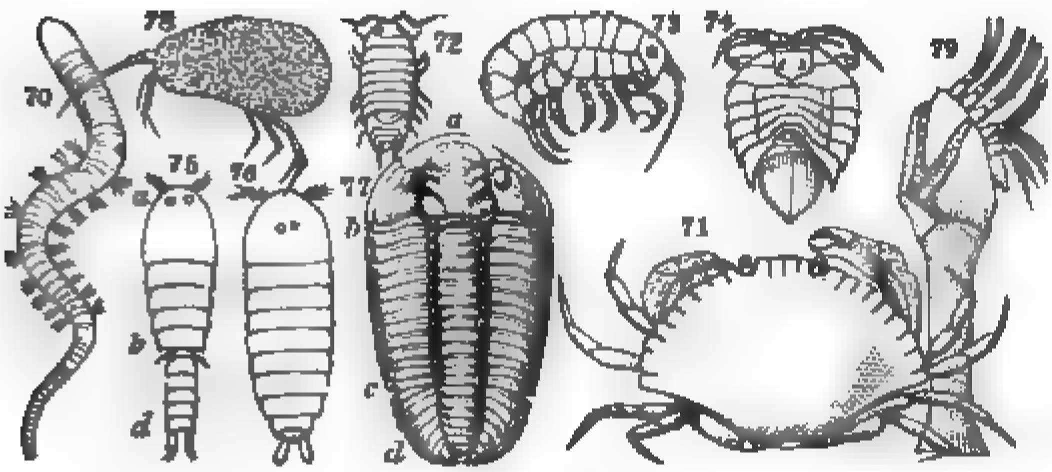


The Calamary or Squid, Loligo vulgaris (length of body, 6 to 12 inches); *i*, the duct by which the ink is thrown out; *p*, the "pen."

passes *below* the stomach and intestine, and has usually a ganglion in each segment of the body,—so that the articulate structure is indicated by the nervous system as well as by the joints of the body and its members. The fundamental element of the body is, hence, a segment or ring containing a nervous ganglion and a portion of the viscera. In some worms the segments are so far independent that the animals multiply by spontaneous fission.

Some of the Articulates are shown in figs. 170 to 179. Fig. 170 is a sea-shore worm; 171, a Crab; 172 to 177, other Crustaceans; 178,

Figs. 170–179.



ARTICULATES, figs. 170–179.—1. *Worms:* 170, Arenicola piscatorum, or Lob-worm (× ½). 2. *Crustaceans:* 171, Crab, species of Cancer; 172, an Isopod, species of Porcellio; 173, an Amphipod, species of Orchestia; 174, an Isopod, species of Serolis (× ½); 175, 176, Sapphirina Iris; 175, female, 176, male (× 6). 177, Trilobite, Calymene Blumenbachii; 178, Cythere Americana, of the Cypris family (× 12); 179, Anatifa, of the Cirriped tribe.

another Crustacean, having a shell like a Mollusk, but showing that it is a true Articulate in having its legs and antennæ jointed, as well as the body within the shell; 179, representing a Cirriped, is also somewhat like a Mollusk in its shell,—though articulate in structure, as the legs show, and, in fact, a Crustacean. Centipedes, and all Insects, as well as Worms, are other examples of Articulates. The name of the sub-kingdom is from *articulus, a joint.*

IV. **Vertebrates.**—Having (1) a jointed internal skeleton, and (2) a bone-sheathed cavity along the back for the great nervous cord, distinct from the cavity for the viscera: as in *Fishes, Reptiles, Birds, Quadrupeds.*

The skeleton is made up of vertebræ, or the bones of the vertebral column, with their appendages; and a vertebra is the fundamental element of the structure. The bone-sheathed cavity occupied by the nervous cord is enclosed by processes from the upper (or dorsal) side of the vertebræ, and the visceral cavity by the ribs, which are processes from the lower side of the vertebræ. The legs and arms are appendages to the system of vertebræ and ribs.

Recapitulation.—In Radiates the structure is radiate or flower-like. In Mollusks it is bag-like and simple. In Articulates it is made of a series of rings, and is composite both in the structure of the skeleton and the nervous system. In Vertebrates it is made

of a series of vertebræ, and is hence composite in the skeleton but essentially simple in the nervous system.

V. **Protozoa.**—Besides the species above included, there are others, of extreme simplicity of structure, which are sometimes referred to the Radiates and sometimes to a separate group, called *Protozoa* (from πρωτος, *first*, and ζωον, *animal*). They embrace some of the microscopic organisms or animalcules, and also the Sponges. They have, in general, no proper mouth or stomach.

Subdivisions of the Sub-Kingdoms.

[Details relating to the higher groups are given as follow: *Fishes*, p. 277; *Reptiles*, p. 343; *Mammals*, p. 421.]

I. Vertebrates.

Four classes are generally recognized:—

1. *Mammals.*—Species suckling their young,—a characteristic peculiar to this highest branch of the animal kingdom: all are warm-blooded and air-breathing. *Examples:* ordinary Quadrupeds, large and small, with Whales and Seals.

2. *Birds.*—Warm-blooded and air-breathing; oviparous; covered with feathers, and adapted for flying.

3. *Reptiles.*—Cold-blooded, air-breathing; oviparous; skin naked or covered with scales, as the Crocodile, Lizard, Frog.

4. *Fishes.*—Cold-blooded; breathing by means of gills; skin naked or covered with scales.

II. Articulates.

The classes are five in number,—three of them—*Insects*, *Spiders*, and *Myriapods*—aerial in respiration; the other two—*Crustaceans* and *Worms*—breathing by means of gills, and living in water or moist earth.

A. Respiration through breathing-holes (spiracles) along the sides or posterior part of the body; admitting air to circulate in the interior. Essentially land or aerial species.

1. *Insects.*—The body in three parts,—a head, thorax, and abdomen distinct; only three pairs of legs. *Examples:* the Beetle, Wasp, Fly, Butterfly.

2. *Spiders.*—The body in two parts, the head and thorax not distinct; four pairs of legs. *Examples:* the Spider, Tick, Scorpion.

3. *Myriapods.*—The body worm-like in form, the head not prominently distinct from the rest; legs numerous. *Examples:* the Centipede.

B. Respiration aqueous or by means of gills,—unless the specie so minute that the surface of the body is equivalent to a gill in action. Essentially water-species, living either in water or mo places.

4. *Crustaceans.*—The body in two parts,—an anterior, called *cephalothorax*, consisting of a head and thorax, the posterior call the *abdomen;* locomotion by means of jointed organs. *Examples:* Crab, Lobster, Shrimp.

5. *Worms.*—Worm-like in form, without any division into cepha thorax and abdomen; the body fleshy; no jointed legs, thou often furnished with tubercles, lamellæ, or bristles. *Examples:* Earth-worm, Leech, Serpula, Intestinal Worm.

The water-species of Articulates commence in the Silurian, a are here further explained.

Crustaceans.—Among Crustaceans there are three orders:—

The *first*, or highest, *ten-footed* species, or *Decapods;* as Crabs (171) and Lobsters.

The *second*, *fourteen-footed* species, or *Tetradecapods* (figs. 172, 1 174).

The *third* and lowest, irregular in number of feet, and unli the Tetradecapods, also, in not having a series of appendages the abdomen: the species are called *Entomostracans*, from the Gre for *insects with shells*.

(*a.*) Among the *Decapods*, Crabs are called *Brachyurans*,—from the Greek short-tailed, the abdomen being small and folded up under the body; the L sters and Shrimps, *Macrourans*,—from the Greek for long-tailed, the abdom being as long as the rest of the body.

(*b.*) Among the *Tetradecapods*, figs. 172, 174 represent species of the tribe *Isopods* (a word meaning equal-footed), and fig. 173 of that of *Amphipods* (of two kinds, abdominal as well as thoracic). Fig. 172 is the Sow-bug, co mon under stones and dead logs in moist soil. Fig. 174 is the Sand-flea, ab dant among the sea-weed thrown up on a coast. In figs. 172, 174 (Isopo the abdomen is abruptly narrower than the cephalothorax; its appenda underneath are gills. In fig. 173 (Amphipod) the abdomen is the part of body after the eighth segment; its appendages are swimming legs and stylets the gills in the Amphipods being attached to the bases of the true legs, and to the abdomen.

(*c.*) Among *Entomostracans* the forms are very various. The absence o series of abdominal appendages is the most persistent characteristic. The e in a few species have a prominent cornea: but in the most of them the cor is internal and there is no projection. In the *Cyclops group* the species h often a shrimp-like form, as in fig. 175, though usually minute. Sometimes male and female differ much in form: 176 is male and 175 female of the *Sapp rina Iris; a b* is the cephalothorax, and *b d* the abdomen. There are legs

the under surface of the anterior part, fitted for grasping, and others behind these, for swimming. In the *Caligus group* the species resemble 176, but the mouth is trunk-shaped and movable. In the *Cypris group* the animal is contained in a bivalve shell, as in fig. 178, and they are hence called *Ostracoids*. They are seldom a quarter of an inch long. In the *Daphnia group* the body has a bivalve shell as in Cypris, but the shell does not cover the head or close at the margin. In the *Limulus group*—containing the Horseshoe of the sea-coasts of the United States—there is a broad, shield-like shell, and a number of stout legs, the basal joints of which serve for jaws. In the *Phyllopod group* the form is either shrimp-like, approaching Cyclops, or like Daphnia or Cypris; but the appendages or legs are foliaceous and excessively numerous: the name is from the Greek for leaf-like feet. In the *Cirriped* or *Barnacle group* the animal has usually a hard, calcareous shell, and is permanently attached to some support, as in the *Anatifa* (fig. 179) and *Barnacle*. The animal throws out a number of pairs of slender jointed arms looking a little like a curl, and thus takes its food,—whence the name, from the Latin *cirrus, a curl*, and *pes, foot*. The Anatifa has a fleshy stem, while the ordinary *Barnacle* is fixed firmly by the shell to its support.

Trilobites.—The *Trilobites* (fig. 177, and also 245 and 320, 322), which occur only fossil, have a resemblance both to the Entomostracans and the Tetradecapods. The similarity to fig. 174 (a Serolis) among the latter is apparent; but they are supposed to be still nearer the Entomostracans, and especially the group called Phyllopods, in which the legs are thin-foliaceous and very numerous,—for no remains of legs are found with any Trilobites, which would not be the case if they had had the stout legs common to Crustaceans of the same size. It is possible that the abdomen (*c d*, in fig. 177) had, beneath, a series of appendages; and, if so, they differed from all known Entomostracans, and approximated to the Tetradecapods. The division of the body longitudinally into three lobes, to which the name *trilobite* refers, is in some species very indistinct, and there is in no case more than a mere depression and suture.

In the *Trilobite* the shell of the head-portion (*a b*, fig. 177) is usually called the *buckler;* the tail- (or properly abdominal) shield, when there is one (fig. 320), the *pygidium*. The buckler (*a b*) is divided by a longitudinal depression into the *cheeks*, or lateral areas, and the *glabella*, or middle area (fig. 177). The cheeks are usually divided by a suture extending from the front margin by the inner side of the eye to either the posterior or the lateral margin of the shell. In fig. 177 (*Calymene Blumenbachii*) this suture terminates near the posterior outer angle. The glabella may have a plane surface, or be more or less deeply transversely furrowed (fig. 177), and usually with only three pairs of furrows.

Worms.—Worms are divided into—

(1.) *Dorsibranchiates*, or *free* sea-worms, having in general short branchial appendages along the back. Many swim free in the open sea, and others live in the

sands of sea-shores or the muddy bottom. The *Arenicola* family includes species that burrow in the sands of sea-shores. Fig. 170 represents the *A. piscatorum*, or Lob-worm, which is common on European shores, and grows to the size of the finger. One species of Eunice has a length of four feet.

(2.) The *Tubicola*, or Serpula tribe, which live in a calcareous or membranous tube and have a delicate branchial flower, often of great beauty, near the head. They are confined to salt water. The tubes often penetrate corals, and the branchial flower comes out as a rival of the coral polyps around it.

(3.) The *Terricola* (Oligochæta), or Earth-worm tribe, destitute of branchial appendages; as the common Earth-worm.

(4.) The *Suctoria*, or Leech tribe; sucking-worms; as the Leech.

Besides these there are the *Helminths*, including most *Intestinal worms*, and the *Turbellaria*.

III. Mollusks.

The Ordinary Mollusks are usually divided into—

(1.) The *Acephals*, or *headless Mollusks;* as the *Oyster* and *Clam;*

(2.) The *Cephalates*, having a head; as the *Snail;* and,

(3.) The *Cephalopods*, having the head furnished with feet; as the *Cuttle-fish*.

The headless species have a mouth, but no perfect organs of sight; the Cephalates have distinct eyes and a distinct head (fig. 166); the Cephalopods have the eyes large, and can grasp with great power by means of their arms (fig. 169). These arms correspond to mouth-appendages or palpi (feelers) in other Mollusks.

The fleshy body of Mollusks has on either side a loose skin or fleshy leaflet starting from the back, which covers the sides of the body like a cloak, and is either open or closed along the venter: it is called the *mantle* or *pallium* (cloak). This mantle lies against the shell in the oyster, clam, and allied species, and secretes it; and in the univalves it is reflexed over more or less of the exterior of the shell, and performs the same function. It enables the animal to give the ornament in color and form which is found over the exterior of many univalves.

1. Cephalopods, or Cuttle-fish tribe.—The shells of this tribe are distinguished almost invariably by having transverse partitions,—whence they are called *chambered* shells (fig. 168). They may be either straight or coiled; but with few exceptions they are coiled in a plane, instead of being spiral. A tube, called a *siphuncle*, passes through the partitions; and this siphuncle may either be central or nearly so, as in the genus *Nautilus* (fig. 168), or lie along the inner or *ventral* side of the cavity, or the outer or *dorsal* side, as in *Ammonites*. The animal occupies the outer chamber, as in fig. 168.

The mouth of the Cephalopods has generally a pair of horny mandibles, like the beak of a hawk in form; and these fossil beaks have been called *Rhyncholites*.

These chambered shells containing Cephalopods were once extremely numerous; but only half a dozen living species are known, and these are of the genus *Nautilus*. Modern Cephalopods are almost exclusively *naked* species, having an *internal* shell, if any. In a few species, as in the genus *Spirula*, the internal shell is chambered and coiled (the coils not touching); but in the rest it is straight, and serves only to stiffen the soft body. In the Cuttle-fish it is spongy-calcareous. In the Squid, or Calamary,—a more slender animal, requiring some flexibility for its movements,—it is horny, and is called the pen (*p*, fig. 169). In some cases it has a small conical cavity at the lower end. In the Belemnite, a group of fossil species, it was stout, cylindrical, and calcareous, with a deep conical cavity, and on one side the margin was prolonged into a thin blade (figs. 702, 703).

The Cephalopods are divided into—

(1.) *Dibranchiates*, having two gills or branchiæ, as in the Octopus, Cuttle-fish, Squid, Belemnite, Spirula, Argonaut,—including, therefore, all existing naked Cephalopods, besides the Argonaut (the Paper-nautilus), whose shell is peculiar in not being chambered.

(2.) *Tetrabranchiates*, having *four* gills, as the name implies; as in the Nautilus and the chambered shells of ancient time. The Orthoceras (figs. 257, 313, 314) was a straight form with plane septa or partitions: the name is from the Greek for *straight horn*. The *Nautilus* is a coiled form with plane partitions, and the siphuncle *central* or *subcentral*. The Ammonite group (figs. 700, 701, 765, 766) contains coiled straight forms with the partitions plaited or zigzag (fig. 765 *b*) at the margin, and a *dorsal* siphuncle.

2. **Cephalates.**—The Cephalates are divided into two groups:—

(1.) The *Gasteropods*, the group containing the *Univalve* shells, as well as some related species without shells,—the animals of which crawl on a flat spreading fleshy piece called the *foot* (fig. 166); and hence the name, from the Greek, implying that they use the *venter* or under surface for a foot.

(2.) The *Pteropods*, which swim by means of wing-like appendages to the head (fig. 167),—to which the name refers, meaning *wing-footed*.

The Gasteropods, which embrace nearly all the cephalate Mollusks, have usually a spiral shell, as in the common Snail, Buccinum, Turbo, etc. The mantle of the animal is sometimes prolonged into a tube or siphon in front, to convey water to the gills; and in this case the shell has a *canal* at the beak for the passage of the siphon. The modern marine univalves without a beak, the Natica

group excepted, are herbivorous, while those having a beak are as generally carnivorous.

3. **Acephals, or Headless Mollusks.**—There is but one group.

Conchifers or ordinary Bivalves, also called *Lamellibranchiates*.—These common species are well known as *bivalves*. Between the mantle or pallium and the body of the animal lie the lamellar branchiæ, or gills, as is obvious in an oyster; and hence the name *Lamellibranchiates*. In a shell like fig. 163, the mouth of the animal faces almost always (except in some species of *Nucula* and *Solemya*) the margin *a*, or the side of the *shorter* slope; and *a* is therefore the *anterior* side, *b* the *posterior;* and, placing the animal with the short slope in front, one valve is the *right*, and the other the *left*. The hinge is at the back of the Mollusk.

On the lower margin of the animal, towards the front part, there is in the Clam and many other species a tough portion which is called the *foot:* it is used, when large, for locomotion, as in the fresh-water Clam; when small, it sometimes gives origin to the byssus by which shells like the Mussel are attached. It is wanting, or nearly so, in the Oyster.

The mantle is sometimes free at the lower margin, as in the Oyster; sometimes the edges of the two sides are united, making a cavity about the body open at the ends; in other cases this cavity is prolonged into a tube or siphon, or into two tubes projecting behind, one receiving water for the gills and the other giving the water exit. The shell is closed by one muscle in the Oyster, etc., by two in the Clam, etc. The species with two muscles are called *Dimyaries*,—from the Greek for *two muscles;* and those with one, *Monomyaries*,—from the Greek for *one muscle*.

These different peculiarities of the animal are partly marked on the shell. In figs. 163, 164, the two muscular impressions are seen at 1 and 2; the impression of the margin of the mantle (*pallial impression*, as it is called) at *p p*; and in fig. 164 the siphon is indicated by a deep sinus in the pallial impression at *s*. In 165, the shell of an oyster, there is only one muscular impression. It is observed also that in fig. 163 about one-third of the animal would be anterior to a vertical line (*m*) let fall from the hinge; whereas in the *Oyster, Avicula, Mytilus*, and related species, the animal is almost wholly *posterior* to this line: in other words, the Oyster is all venter, while the Clam is a higher type in the order of Acephals.

The remaining Mollusks are of a distinct type, namely:—

The ANTHOID Mollusks, many having stems like flowers.

1. *Ascidians*, or *Tunicates*.—These Mollusks are enclosed in a leathery skin instead of a shell. They do not occur fossil.

2. *Bryozoans*.—The Bryozoans, or *moss-animals* (so named from the moss-like corals they often form), look like polyps, as represented in figs. 162, 162 *a*. 162 is magnified about eight times. The corals consist of minute cells, either in branched, reticulated, or incrusting forms, and are common in the Silurian as well as later rocks

and in existing seas. Fig. 162 *a* represents the animal, showing its stomach at *s*, and the flexure in the alimentary canal, with its termination alongside of the mouth. *Eschara*, *Flustra*, *Retepora*, are names of some of the genera.

3. **Brachiopods.**—The Brachiopods (figs. 160, 161, and 216 to 227) have a bivalve shell, and in this respect are like ordinary bivalves. But the mouth of the animal faces *the middle of the lower margin* (*a*); and the shell, instead of covering the right and left sides, covers the dorsal and ventral sides, or its plane is at right angles to that of a clam. Moreover, the shell of a Brachiopod *is symmetrical in form, and equal either side of a vertical line a b*. The valves, moreover, *are almost always unequal; the larger* is the *ventral*, and the other the *dorsal*. There is often an aperture at the beak (near *b*, fig. 160) which gives exit to a pedicel by means of which the animal fixes itself to some support. In fig. 161, representing a species of the genus *Lingula*, the fleshy support is a long one, and the shell stands like a plant, with the opening upward.

These Brachiopods are also peculiar in other points of structure. They have a *pallium*, but no independent branchial leaflets. They have a pair of coiled and fringed *arms*, which they sometimes extrude (fig. 216),—whence the name Brachiopod, meaning *arm-like foot*. For the support of these arms there are often bony processes in the interior of the shell, of diverse forms in different genera (figs. 208, 212, and 215).

IV. Radiates.

The sub-kingdom of Radiates contains *three* classes:—

1. Echinoderms.—Having the exterior more or less calcareous, and often furnished with spines and distinct nervous and respiratory systems and intestine, as the *Echinus* (fig. 153), *Star-fish* (fig. 154), *Crinoid* (fig. 155). The name is from *echinus, a hedgehog*, in allusion to the spines.

2. Acalephs.—Having the body usually nearly transparent or translucent, looking jelly-like. Internally a stomach-cavity, with radiating branches; also a circular nervous cord. *Ex.*, the Medusa, or Jelly-fish (fig. 150). They generally float free, with the mouth downward.

3. Polyps.—Fleshy animals, like a flower in form, having above, as seen in figs. 147, 148, a disk with a mouth at centre and a margin of tentacles; internally, a radiated arrangement of fleshy plates; and living for the most part attached by the base to some support. *Ex.*, the *Actinia*, or *Sea-Anemone*, and the *Coral animals*.

All these classes commence in the Lower Silurian; and some of their subdivisions are therefore here mentioned.

1. **Echinoderms.**—The subdivisions of Echinoderms are as follow:—

1. *Holothurioids.*—Having the exterior soft, and throughout extensile or contractile, and the body stout, subvermiform in shape. The group is not known among fossils. It includes the *Biche de mar*, or *Sea-slug.*

2. *Echinoids.*—Having a thin and firm hollow shell, covered externally with spines (fig. 153); form, flattened spheroidal to disk-shape; the mouth below, at, or near the centre, as the Echinus, fig. 153.

3. *Asterioids.*—Having the exterior stiffened with calcareous pieces, but still flexible; form, star-shaped and polygonal; mouth below, at centre; animal free, except in the young state. *Ex.*, the Star-fish, fig. 154.

4. *Crinoids.*—Crinoids are related to the Asterioids and Echinoids, but have, with few exceptions, a permanent stem or pedicel, as figs. 155, 156, 158. They are thus like the young Asterioids. The stem is attached to the back, and they stand with the mouth upward. Fig. 155 represents the Crinoid closed, like a closed bud; when opened, it would appear like an opened flower, and each ray would be seen to be delicately fringed, as in fig. 158.

A. *Echinoids.*—Fig. 153 represents an echinus partly uncovered of its spines, showing the shell beneath, and 157 another, wholly uncovered. The shell consists of polygonal pieces in twenty vertical series arranged in ten pairs. *Five* of these ten pairs are perforated with minute holes, and are called the *ambulacral* series (*a* in fig. 153 represents one pair); and the other five alternating with these are called the *inter-ambulacral* (*b*). The inter-ambulacral areas have the surface covered with tubercles, and the tubercles bear the spines, which are all movable by means of muscles. The ambulacral have few smaller tubercles and spines, or none; but over each pore (or rather each pair of pores) the animal extends out a slender fleshy tentacle or feeler, which has sometimes a sucker-like termination and is used for clinging or for locomotion. The ambulacral areas are thus distinguished from the others by being generally much narrower, by having smaller spines or none, and by having a multitude of these tentacles or feelers,—the use of which is partly for aiding the animal in its motions, partly for seizing food, and partly to supply vesicles in the interior with water for the purposes of respiration. In

fig. 157 the inter-ambulacral areas are broad and the plates large, but the ambulacral are narrow and the plates indistinct.

The *mouth*-opening is situated below at the centre of radiation of the plates.

The *anal* opening in the *Regular* Echinoids (fig. 153) is at the opposite or dorsal centre of radiation. Around the anal opening there are five minute ovarian openings.

In the *Irregular* Echinoids—constituting a large group—the *anal* opening is to one side of this dorsal centre of radiation, and often on the ventral or under surface of the animal. In fig. 157, for example, the anal opening is marginal instead of central, while the ovarian pores are at the dorsal centre, as in the *Regular* Echinoids.

To one side of the dorsal centre (to the right of the front side), in the Regular Echinoids, there is a small porous prominence on the shell, often called the *madreporic* body, from a degree of resemblance in structure to coral. In the *Irregular* Echinoids this madreporic body is *in* the centre of dorsal radiation.

The ambulacral areas are sometimes perforated through their whole length. But in other cases only a dorsal portion is perforated, as in fig. 157, and, as this portion has in this case some resemblance to the petals of a flower, the ambulacra are then said to be *petaloid*. A large part of the Echinoids have a circle of five strong, calcareous jaws in the mouth; in another portion there are *no* jaws.

The Echinoids have been divided into—

I. *Regular Echinoids.*

1. *Cidaris Family.*—Having the inter-ambulacral spaces consisting of two series,—the general fact in Echinoids, as above stated.

2. The *Archæocidaris Family*, having the inter-ambulacral spaces consisting of more than two series of plates—a peculiarity confined to the Palæozoic Echinoids.

II. *Irregular Echinoids.*

1. *Galerites Family.*—Mouth-opening central, furnished with jaws; ambulacral area perforate throughout. (Found only fossil.)

2. *Clypeaster Family.*—Like the preceding, but ambulacra petaloid. (Fossil and recent.)

3. *Echinoneus Family.*—Like the Galerites family, but no jaws. (Recent.)

4. *Cassidulus Family.*—Like the Clypeaster family, but no jaws. (Fossil and recent.)

5. *Spatangus Family.*—Mouth-opening not central, and having a bilabial form instead of round or stellate; ambulacra petaloid; no jaws. (Fossil and recent.)

6. *Dysaster Family.*—Ambulacral areas not radiating from a common area on the back, but two dorsally distant from the others. Whether there were jaws or not is undetermined. (Fossil.)

B. *Asterioids.*—The Asterioids (Star-fishes) have the mouth below and there are ambulacral pores and sucker-feelers along the midd' of the under surface of the rays. The groups are,—

1. *Asterias Family* (*Asteridæ*).—Rays broad; viscera extending ir the rays.

2. *Ophiura Family* (*Ophiuridæ*).—Rays slender and very flexible; viscera confined to the central disk of the Star-fish, as in *Ophiura*.

3. *Comatula Family* (*Comatulidæ*).—Rays narrow, often much subdivided; a small supplementary series of arms on the back for clinging; and the animal usually attached by these dorsal arms so as to have the mouth upward, unlike other Asterioids, as in the genus *Comatula*.

C. *Crinoids*.—There are two tribes:—

1. The *Crinidea* or *Encrinites*.—Having a regular radiate structure, and the arms proceeding from the margin of the disk, as in figs. 155 and 158.

2. *Cystidea* (from the Greek for *a bladder*), fig. 156. Radiate arrangement of the plates not distinct. Arms when present proceeding from the centre of the summit instead of the margin of a disk; in some only two arms; often wanting, and replaced by radiating ambulacral channels, which are sometimes fringed with pinnules.

The Crinids closely resemble a *Comatula;* only they have a stem, instead of the short arms, for attachment. The stem consists of calcareous disks like button-moulds in form, set in a pile together, and hence in the living animal it has some flexibility. Fig. 158 represents a modern Crinid (*Pentacrinus Caput-Medusæ*) from the West Indies. The mouth is at the centre between the arms. Fig. 155 *a* represents the form of one of the disks of the stem in an extinct Crinid. The disks in Palæozoic species are generally round or oval; and they were the same also in many later species. Pentagonal disks commence in the Lower Silurian, and are most common in the Mesozoic formations. The pentagonal forms represented in fig. 158, *a*, *b*, *c*, *d*, pertain to the Pentacrinus family, the only family of Crinids now known to exist.

In ancient Crinids or Encrinites, the arms are not free down to the pedicel, but there is a union of their lower part, either directly or by means of intermediate plates, into a cup-shaped *body* or *calyx* (as in fig. 155, and also figs. 527, 528, under the Carboniferous age).

In fig. 159, the plates of one of these cups in the species *Actinocrinus longirostris* H. are spread out, the bottom plates of the cup being at the centre. The plates, it is seen, are in five radiating series, corresponding to the five rays or arms of the Crinid, and between are intermediate pieces. The three plates numbered 1 are called the *basal*, as the stem is articulated to the piece composed of them; 3, 3, 3 are the *radial;* 4, 4, *supra-radial;* 5, *brachial*, situated at the base of the arms; 7 are intermediate plates, called *inter-radial;* 8, another intermediate, the *inter-supraradial*. Sometimes, in other Crinids, there is another series of plates, at the junction of the plates 1 and 3, called *sub-radials*. Finally,

the anal opening of a Crinid is situated on one side of the body, it being lateral, as in the Echinoid in fig. 157; and the intermediate group of plates numbered 10 are called the *anal*.

Nearly all the Palæozoic Crinoids have the anal and oral apertures together, there being but a single opening in the summit (*Cyathocrinus* is said to be an exception). This opening is sub-central (fig. 524) or lateral (fig. 525), and in the former cases is often (as in many species of Actinocrinus) situated at the summit of a slender proboscis made up of small pieces and sometimes three or four times as long as the body. In some species of *Poteriocrinus* (*P. Missouriensis* Shumard = *P. longidactylus*, Shumd. Mo. Rept., p. 188), the proboscis is very large, being nearly as wide as the body and four or five times as long. It is composed of regular ranges of hexagonal plates, with a series of pores between every alternate range, much like the ambulacral pores in the true *Echinoids*.

In the Cystids the aperture is generally lateral and remote from the top, as in fig. 156, while the arms come out often from the very centre.

The Cystids are also peculiar in what are called *pectinated rhombs* (see fig. 156); that is, rhombic areas crossed by five bars and openings: the use of them is uncertain,—though they are probably connected with an aquiferous system and respiration. The Cystids are the most anomalous of Radiates.

Among the Crinidea there are—first, the species with arms and rounded stems, which are of several genera and families. Second, the *Pentacrinus* group, which also have long arms, but the stems are five-sided. Third, the *Blastoids*, which have round stems, but the body is pentagonal and flower-like or petaloid in its divisions, and the divisions are furnished with pinnules: *Ex.*, the *Pentremites*. As they are usually found closed up, they have a resemblance to a flower-bud; and hence the name, from the Greek.

2. **Acalephs.**—Besides the jelly-like Acalephs, which have very rarely left any traces in the strata, there are delicate coral-making species of the Hydroid group. Fig. 151 represents a *Hydra*, much enlarged; 152, a related animal of the *Tubularia* family (genus *Syncoryna*). Other species, having animals like 151, as in the genera *Campanularia* and *Sertularia*, form very delicate membranous coralla, which under the microscope consist of series of minute cells; and the fossils called *Graptolites* have been compared to them. The hard, stony corals called *Millepores* have been shown by Agassiz to have animals like fig. 152, and therefore to belong to the class of Acalephs. The genera of fossil corals *Chætetes* and *Favosites*, having the cells divided by horizontal partitions, and being in this respect like Millepores, he refers to the same group.

There are, hence, not only stony corals made by Polyps, as in the common kinds, but there are also large stony corals made by Acalephs, besides delicate kinds which were made either by Hydroid Acalephs or Bryozoan Mollusks.

3. **Polyps.**—There are two groups of Polyps:—

1. ACTINOID POLYPS, illustrated in figs. 147, 148, and all ordinary corals. The rays of the polyps are of variable number, and naked (not fringed).

The coral is secreted within the polyps, as other animals secrete their bones. *It is internal, and not external.* It is usually covered with radiate cells, each of which corresponds to a separate polyp in the group. The rays of a cell correspond to fleshy partitions in the interior of the polyp, and the cavity of a cell is the space occupied by the stomach and visceral cavity: it is not, therefore, a cavity into which the polyp retreats; it is the inside of the polyp itself. The material is carbonate of lime (limestone); and it is taken by the polyp from the water in which it lives, or from the food it eats.

2. ALCYONOID POLYPS, illustrated in fig. 149, and the Gorgonia and Alcyonium corals. The rays of the polyps are *eight* in number, and fringed. The figure represents a part of a branch of a Gorgonia (Sea-Fan), with one of the polyps expanded. The branch consists of a black horny axis and a fragile crust. The crust is partly calcareous, and consists of the united polyps; the axis of horn is secreted by the inner surface of the crust. The Precious Coral used in jewelry comes from the shores of Sicily and Southern Italy, and belongs to this Alcyonoid division. It is related to the Gorgonias, but the axis is red and stony (calcareous) instead of being horny, and this stony axis is the coral so highly esteemed.

Among the Actinoid Polyps there are the following groups,—exclusive of those that do not secrete coral:—

1. *The Actinia tribe.*—The number of rays a multiple of *six.* It includes the Astræa family, Oculina family, Fungia family, Caryophyllia family, Madrepora family, Porites family.

2. *The Cyathophyllum tribe.*—The number of rays a multiple of *four.* It contains only Palæozoic corals, replacing in that era the Astræoid corals of later eras. The animals were probably like the Actinia in fig. 147.

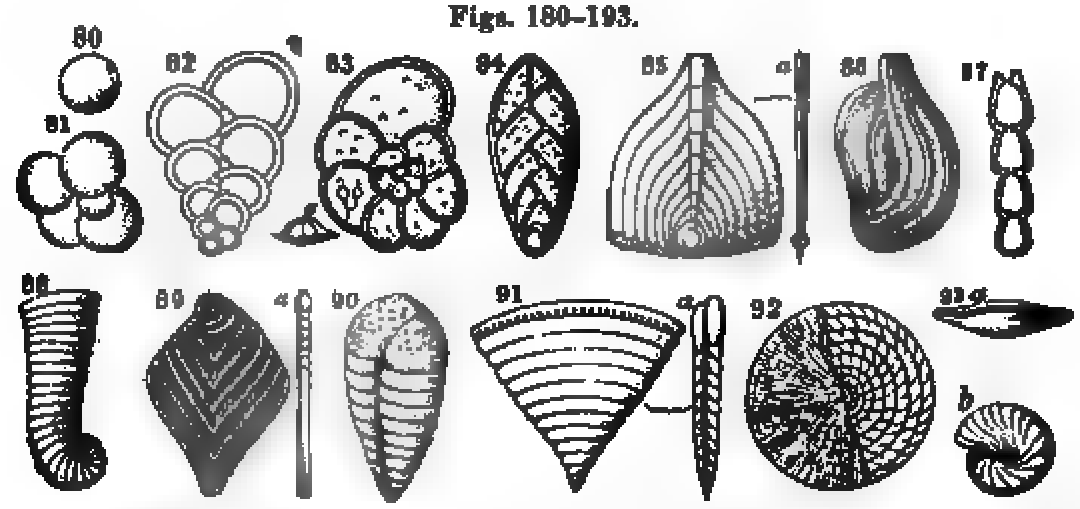
V. PROTOZOANS.

The groups of Protozoans of special interest to the geologist are two:—

1. **Rhizopods**, or **Foraminifers.**—Species mostly microscopic, forming calcareous shells. These shells, with few exceptions, are very minute,—many times smaller than the head of a pin; and yet they have contributed largely to the formation of limestone strata. They consist of one or more cells; and the com-

pound kinds present various fanciful shapes, as illustrated in the annexed cut.

Figs. 180–193.



Figs. 180 to 193.—RHIZOPODS, much enlarged (excepting 192, 193). Fig. 180, Orbulina universa; 181, Globigerina rubra; 182, Textilaria globulosa *Ehr.*; 183, Rotalia globulosa; 183 *a*, Side-view of Rotalia Boucana; 184, Grammostomum phyllodes *Ehr.*; 185, *a*, Frondicularia annularis; 186, Triloculina Josephina; 187, Nodosaria vulgaris; 188, Lituola nautiloides; 189, *a*, Flabellina rugosa; 190, Chrysalidina gradata; 191, *a*, Cuneolina pavonia; 192, Nummulites nummularia; 193 *a*, *b*, Fusulina cylindrica. All but the last two magnified 10 to 20 times.

Fig. 180 is a one-celled species; the others are compound, and contain a number of exceedingly minute cells. A few are comparatively large species, and have the shape of a disk or coin, as fig. 192, a *Nummulite*, natural size; the figure shows the interior cells of one-half: these cells form a coil about the centre. *Orbitoides* is the name of another genus of coin-like species. Fig. 193 *a* is a species of *Fusulina*, a kind nearly as large as a grain of wheat, related to the Nummulites; 193 *b* is a transverse view of the same. This is one of the ancient forms of Rhizopods, occurring in the rocks of the Coal formation.

D'Orbigny divided the Rhizopods into (1) the one-celled (called *Monostegæ* by D'Orbigny); (2) shells having the segments in direct linear series, figs. 185, 187 (*Stichostegæ*); (3) shells spiral, the spiral of a single series, figs. 181, 182, 183, 184, 188, 189, 190, 192, 193 (*Helicostegæ*); (4) shells spiral, consisting of alternating segments, genus Robertina, etc. (*Entomostegæ*); (5) shells consisting of alternating segments not spirally arranged, fig. 191 (*Enallostegæ*); (6) segments clustered, without linear or spiral order, about an axis, fig. 186 (*Agathostegæ*). (See Appendix A.)

The cells of Rhizopods are each occupied by a separate animal or zooid, though each is organically connected with the others of the same group or shell. The animal is of the simplest possible kind, having no mouth or stomach or members. It projects at will slender processes of its own substance through pores in the shell.

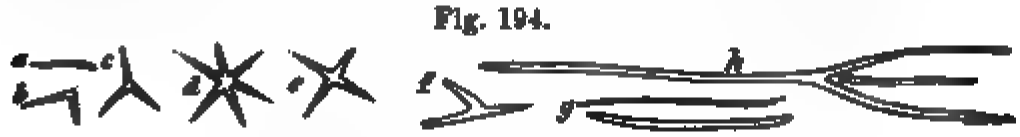
The above are shell-making species of Rhizopods. The name *Rhizopods* comes from the Greek for root-like feet,—in allusion to the root-like processes they

throw out. The shell-making species have been distinguished as *Foraminifera*, from the pores above alluded to. Some of the species not secreting shells (as in the genus *Amœba*) have been seen to extemporize a mouth and stomach. When a particle of food touches the surface, the part begins to be depressed, and finally the sides of the depression close over the particle, and thus mouth and stomach are made when needed; after digestion is complete, the refuse portion is allowed to escape.

The shells of some Rhizopods do not consist of distinct cells: the aggregate living mass secrete carbonate of lime, without retaining the distinction of the zooids. This is the case, as Carpenter has observed, in the Nummulite-like genus *Orbitolites*.

2. **Sponges.** — Sponges are regarded as compound animals, consisting of an aggregate of zooids related to those of the Foraminifera; and the cylindrical water-passages within them have been supposed to answer as stomach-cavities for the Sponge. The material of the Sponge is a little like horn in its nature; its microscopic characters show that it is not vegetable. Besides the general tissue of the Sponge, there are in most species microscopic spicula through the tissues, which are siliceous (figs. 194, *a–h*),—some of

Fig. 194.



Siliceous spicula of Sponges.

them acicular, others with divergent rays. They are in great numbers in some species; and even the fibres of the Sponge are sometimes siliceous. In some few species the spicula are calcareous.

There are other siliceous microscopic organisms, called *Diatoms;* but these are regarded as vegetable in nature, and are mentioned on p. 167.

2. VEGETABLE KINGDOM.

The vegetable kingdom is not divisible into sub-kingdoms like the animal; for the species all belong to one grand type, the Radiate, the one which is the lowest of those in the animal kingdom. The higher subdivisions are as follow:—

I. Cryptogams.—Having no distinct flowers or proper fruit, the so-called seed being only a *spore*, that is, a simple cellule without the store of nutriment (albumen and starch) around it which makes up a true seed; as the Ferns, Sea-weed. They include—

1. *Thallogens.*—Consisting wholly of cellular tissue; growing in fronds without stems, and in other spreading forms; as (1) Algæ, or Sea-weeds; (2) Lichens.

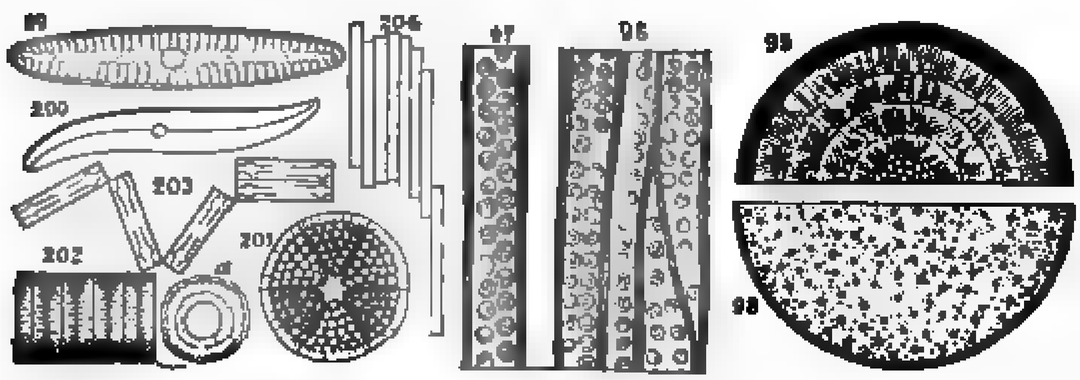
2. *Anogens.*—Consisting wholly of cellular tissue; growing up in short, leafy stems; as (1) Musci, or Mosses; (2) Liverworts.

3. *Acrogens.*—Consisting of vascular tissue in part, and growing upward; as (1) Ferns; (2) Lycopodia (Ground-Pine); (3) Equiseta; and including many genera of trees of the Coal period.

II. Phænogams.—Having (as the name implies) distinct flowers and seed; as the Pines, Maple, and all our shade and fruit trees, and the plants of our gardens. They are divided into—

1. *Gymnosperms.*—Having the flowers exceedingly simple, and the *seed naked*,—the seed being ordinarily on the inner surface of the scales of cones; growth exogenous, the trees having a bark and rings of annual growth (fig. 195); as the Pine, Spruce, Hemlock, etc. The name gymnosperm is from the Greek for *naked seed*.

Figs. 195–204.



Plants.—Fig. 195, section of exogenous wood; 196, fibres of ordinary coniferous wood (Pinus Strobus), longitudinal section, showing dots, magnified 300 times; 197, same of the Australian Conifer, Araucaria Cunninghami; 198, section of endogenous stem.

Figs. 199 to 204, Diatoms highly magnified; 199, Pinnularia peregrina, Richmond, Va.; 200, Navicula sigma, ib.; 201, Actinoptychus senarius, ib.; 202, Gallionella sulcata, ib.; *a*, transverse section of the same; 203, a species of Bacillaria, from the salt water at Stonington, Conn.; 204, Bacillaria paradoxa, West Point.

The wood of the Conifers is simply woody fibre without ducts, and in this respect, as well as in the flowers and seed, this tribe shows its inferiority to the following subdivision. The fibre, moreover, may be distinguished, even in petrified specimens, by the dots along their surface as seen under a high magnifier. The dots look like holes, though really only thinner spaces. Fig. 196 shows these dots in the Pinus Strobus. In other species they are less crowded. In one division of the Conifers, called the *Araucariæ*, of much geological interest, these dots on a fibre are alternated (fig. 197); and the Araucarian Conifers may thus be distinguished.

2. *Angiosperms.*—Having regular flowers and *covered seed;* growth exogenous, the plants having a bark and rings of annual growth (fig. 195); as the Maple, Elm, Apple, Rose, and most of the ordinary

shrubs and trees. These Exogens are called *Angiosperms*, because the seeds are in seed-vessels; and also *Dicotyledons*, because the seed has two cotyledons or lobes.

3. *Endogens.*—Regular flowers and seed; growth endogenous, the plants having no bark, and showing in a transverse section of a trunk the ends of fibres, and no rings of growth (fig. 198); as the Palms, Rattan, Reed, Grasses, Indian Corn, Lily. The Endogens are *Monocotyledons;* that is, the seed is undivided, or consists of but one cotyledon.

Only the salt-water species of plants—Algæ, or Sea-weeds—are known to occur in the Silurian. Among the fossil Algæ there are two prominent kinds:—

1. *Fucoids.*—Related to the tough, leathery sea-weeds of sea-coasts, which are called *Fuci*, and which grow in great profusion in some seas, attaining a length at times of several rods.

2. *Protophytes*, or infusorial species.—Mostly unicellular plants. The *Diatoms* are microscopic species which have a siliceous shell; and they grow so abundantly in some seas that they are producing large siliceous accumulations. A few of these siliceous species are figured above, in figs. 199 to 204. The Bacillaria (figs. 203, 204) consist of rectangular segments that close up or slide on one another, as the figures illustrate.

II. PALÆOZOIC TIME.

I. AGE OF MOLLUSKS, OR SILURIAN AGE.

The term Silurian was first applied to the rocks of the Silurian age by Murchison, and is derived from the ancient name Silures, the designation of a tribe inhabiting a portion of England and Wales where the rocks abound. The rocks occur on all the continents and over much of their surface, constituting strata of sandstone, shale, conglomerate, and limestone; and the most of the strata abound in fossils, as shells, corals, and other allied forms.

The subdivisions of the Silurian are not only widely different on the two continents, America and Europe, but also on different parts of the same continent. In American geological history it has been found most convenient to recognize that subdivision into periods and epochs which is derived from the succession of rocks

in the State of New York, where the strata are well displayed and have been carefully studied.

Some standard for our divisions of time must be adopted; and, whatever that standard, it is afterwards easy to compare with it, and bring into parallelism, the successive strata or events of other regions. The State of New York lies on the northeastern border of the great interior,—a vast region stretching southward and westward from the Appalachians, to the Rocky Mountains, and beyond the head-waters of the Mississippi to the Arctic Ocean, over which there were many common changes; and, owing apparently to this situation on the north against the Azoic, and near the head of the Appalachian range, there are indicated a greater number of subordinate subdivisions in the rocks, or of epochs in time, than are recognized to the west. It is, therefore, a more detailed indicator of the great series of changes and epochs in the Palæozoic era, and hence it is especially well fitted to become the basis of a scale or standard for the *subdivision* of time. This will be apparent in the course of the following pages.

The order of succession in the Silurian periods and rocks is shown in the section on page 131 (fig. 134). The numbers affixed to the subdivisions of the section are used for the same formations throughout the work.

Subdivisions of the Silurian.

II. UPPER SILURIAN.

3. LOWER HELDERBERG PERIOD (7).
   Lower Helderberg limestones, including in New York (1) the Water-lime group; (2) the Lower Pentamerus limestone; (3) the Delthyris shaly limestone; (4) the Upper Pentamerus limestone.

In Great Britain, the Ludlow beds, including the Lower Ludlow limestone, the Aymestry limestone, Upper Ludlow limestone. In Norway, Upper Malmö limestones and schists.

2. SALINA PERIOD. (6.)
   Onondaga Salt group.
1. NIAGARA PERIOD (5).
   4. NIAGARA EPOCH (5 *d*): Niagara shale and limestone.
   3. CLINTON EPOCH (5 *c*): Clinton group.
   2. MEDINA EPOCH (5 *b*): Medina sandstone.
   1. ONEIDA EPOCH (5 *a*): Oneida conglomerate.

In Great Britain the Wenlock shale and limestone are referred to the Niagara (5 *d*); the Upper Llandovery, to the Clinton (5 *c*); and the Upper Caradoc sandstone, Coniston grits, Lower Llandovery, to the Medina and Oneida epochs (5 *b* and 5 *a*). Murchison divides the Upper from the Lower Silurian of Britain at

the bottom of the Upper Llandovery; the Upper Llandovery is thus made Upper Silurian, and the lower, Lower Silurian.

In Bohemia, Barrande's formations E to H are referred to the Upper Silurian, consisting of schists, part Graptolitic, with trap. In Norway, Encrinal schists, Coral and Pentamerus limestone, Lower Argillaceous schists.

I. LOWER SILURIAN.

3. Hudson Period (4).
   2. Hudson Epoch: Hudson River shale (4 *b*).
   1. Utica Epoch: Utica shale (4 *a*).

In Great Britain, Lower Caradoc sandstone, and upper part of Llandeilo flags. In Bohemia, part of Barrande's formation D. In Sweden, Orthoceratite limestone and Encrinal schists, flagstone. Angelin's Region D.

2. Trenton Period (3).
   2. Trenton Epoch (3 *b*): Birdseye limestone (3 *b′*), Black River limestone (3 *b″*), Trenton limestone (3 *b‴*).
   1. Chazy Epoch (3 *a*): Chazy limestone.

In Great Britain, Bala limestone and Llandeilo flags. In Bohemia, Barrande's formation D. In Sweden, Angelin's C, Orthoceratite limestone. In Russia, schists and Orthoceratite limestone, called the *Pleta;* Ungulite grit of Pander beneath the limestone.

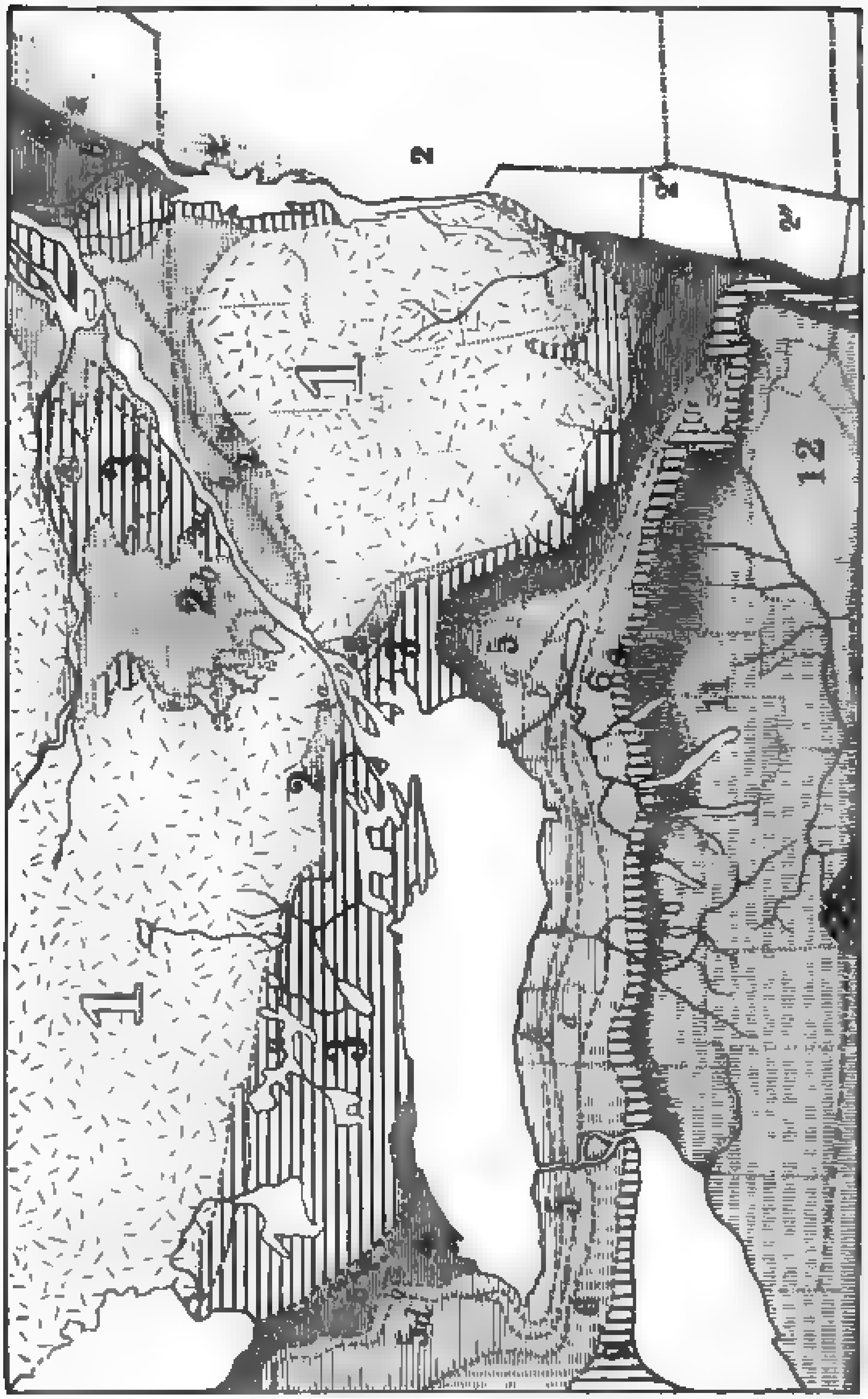
1. Potsdam, or Primordial Period (2).
   2. Calciferous Epoch (2 *b*): Calciferous sandrock in New York. Sandstone with very thick shales and some limestone forming the larger part of the "Quebec" group of Canada and the Taconic of Emmons. Magnesian limestone of the Mississippi valley. Sandstones and Magnesian limestone in Eastern Tennessee.
   1. Potsdam Sandstone (2 *a*): Potsdam sandstone in New York, and sandstone with some limestone in the West. Thick slates, sandstone, and some limestone in and along the Green Mountains and the Alleghanies. Chilhowee sandstones, Tennessee.

In Great Britain, Lingula flags; hard sandstones with schists below at Stiper Stones in Shropshire; Black schists at Malvern; Tremadoc slates; Skiddaw slate. In Bohemia, Barrande's Primordial Zone, C. In Norway and Sweden, Angelin's A and B, Fucoidal sandstone and millstone, Olenus beds, schists.

Explanation of the Geological Map.

The annexed map of New York and a part of Canada exhibits the surface-rocks of the region. As remarked under the Azoic

Fig. 205.



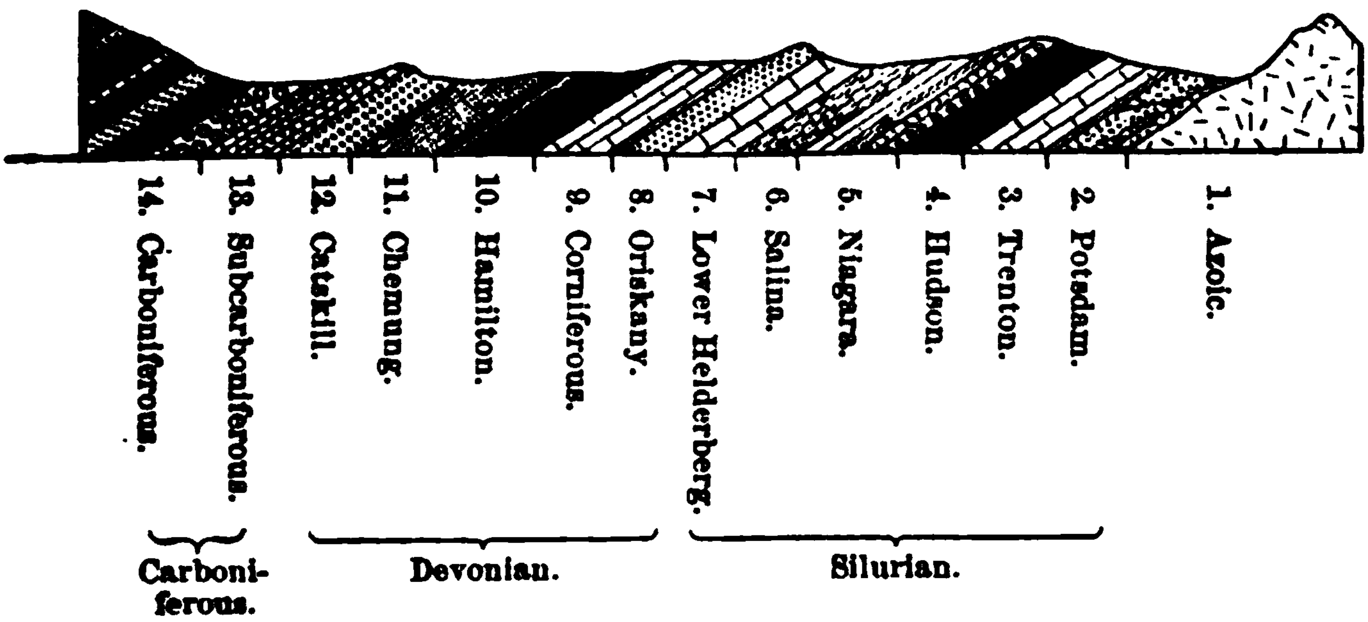
Geological Map of New York and Canada.

(p. 137), the strata of the Silurian and Devonian outcrop in succession on going from the Azoic (No. 1) southward. The numbers on the areas render a comparison with the section and with the tables beyond easy. The Silurian strata are lined *horizontally;* the Devonian, *vertically;* and the subcarboniferous beds, which appear at the southern margin of New York State (No. 13) are cross-lined.

The area 2, which is that of the Potsdam period, is divided into two portions, one distinguished as *a* or 2 *a*, and the other as *b* or 2 *b:* the former is the area of the rocks of the Potsdam epoch, and the latter of the Calciferous epoch, which epochs are elsewhere in the work distinguished by the same numbering. Other areas are similarly divided. As another example, the area 5 (Niagara period) is divided into *a, b, c, d,* corresponding to 5 *a*, 5 *b*, 5 *c*, 5 *d* in the above table. The areas of Nos. 7 and 8 in the series (the Lower Helderberg closing the Silurian, and the first period of the Devonian) are not distinguished on the map from No. 9.

Fig. 206 is an ideal section of the rocks of New York, along a line running *southwestward* from the Azoic on the north across the

Fig. 206.



State to Pennsylvania. It shows the relative positions of the successive strata,—bringing out to view the fact that the areas on the map are only the outcrops of the successive formations. This is all the section is intended to teach; for the uniformity of dip and its amount are very much exaggerated, and the relative thickness is disregarded.

A.—LOWER SILURIAN.

1. POTSDAM OR PRIMORDIAL PERIOD (2).

Epochs.—1. The Potsdam epoch, or that of the Potsdam sandstone (2 *a*). 2. The Calciferous epoch, or that of the Calciferous sandrock (2 *b*).

I. Rocks: kinds and distribution.

1. American.

The Potsdam formation (numbered 2 on the map, p. 170) appears at the surface just south of and adjoining the Azoic areas in New York and the West: the strata here exposed are the outcropping portions of a formation that probably underlies all the fossiliferous rocks of the great Mississippi valley, and stretches south beyond Texas, and north, either side of the Azoic axis of the continent, into the Arctic regions. These Primordial strata have been observed and studied in Texas, about the Black Hills of Dakota and the Laramie Range of the Rocky Mountains, and north in British America. They are also surface-rocks at various places along the Appalachian chain from the St. Lawrence through western Vermont to Alabama and Tennessee. East of this chain, they occur near Boston at Braintree, in Newfoundland, and in Labrador. These strata have hence a wide continental range, a universality of distribution unexceeded among later formations.

The rock of the Potsdam epoch is mostly a laminated sandstone in New York. Along the northern border of the United States, and south, over the Mississippi basin, there is, in addition, some limestone; and a vast thickness of slate or shale exists along the Appalachians from the St. Lawrence southwestward.

The Calciferous epoch, as the name implies, was characterized to a considerable extent by limestone-making, though less strikingly so than the epochs of the Trenton period, which next succeed. The rock is a hard sandstone, more or less calcareous, in New York; a magnesian limestone, with some sandstone, in the Mississippi basin, where it is often called the *Lower Magnesian limestone;* sandstone with very thick shales, and some beds of limestone, along the course of the Appalachians, north and south.

The thickness of the beds of the Potsdam period in New York. Western Canada, and the Mississippi basin, varies usually from 30 to 600 feet; but along the Appalachians the rocks have an enormous development, being from 2000 to 7000 feet thick.

The rocks of the Potsdam period in many places overlie horizontally or nearly so the crystalline Azoic, as illustrated in figs. 136, 137, 138. In 136 the Potsdam sandstone (2 *a*) and Calciferous sandrock (2 *b*) rest upon the folded Azoic of Essex co., N.Y.; and in 138, from Canada, there is the same condition, with also the Trenton limestone (3) and Utica shale (4 *a*) overlying the Potsdam strata. The following cut, from a sketch by J. D. Whitney, represents

the juxtaposition of the Potsdam and Azoic near Carp River, south of Lake Superior; the former rock (on the right in the view), slightly inclined sandstone; the latter (on the left), quartzite in

Fig. 207.

a nearly vertical position, which position it had received before the deposition of the sandstone.

Through New York and the greater part of the Mississippi basin the strata have usually a gentle dip or are nearly horizontal. Along the Appalachian chain, east of Lake Champlain and the Hudson, in the region of New England, of the Alleghanies in Pennsylvania, and of the Cumberland Mountains in Tennessee, they are upturned at all angles to verticality.

1. Potsdam epoch.—*a. Interior Continental basin.*—The Potsdam sandstone in New York varies from a hard quartzite, as at Keeseville, N.Y., and Adams, Mass., to a friable sandstone. Much of it is a good building-stone, as at Potsdam, Malone, and elsewhere, N.Y. The colors are gray, drab, yellowish, brownish, and red. In the West, in Michigan, Wisconsin, and Minnesota, the rock is often so soft as to crumble in the fingers. This want of firmness in one of the most ancient of rocks shows how ineffectual are ordinary waters, even through the lapse of ages, in causing solidification. At some localities it consists of a clean white sand and crumbles readily, making a good material for glass. The rock is sometimes a conglomerate, especially in its lower part, for ten or twelve feet; on the north side of the Azoic in the northwest part of Clinton co. and part of St. Lawrence co., near De Kalb,

and also in Franklin co., N.Y., the conglomerate attains in places a thickness of 300 feet.

On the south shores of Lake Superior, east of Grand Island, the Potsdam epoch is represented by the famous "Pictured" rocks, which form bluffs of 50 to 200 feet on the south shores and are variegated in color with vertical bands and blotches. The color is often a red blotched with light gray, the red being due to oxyd of iron, and the gray to a removal of the previous red color by organic matter; other colors are brown, greenish, and yellowish. Some of the rock is very soft and fragile, and other parts are hard and gritty. The "Pillared" rocks near the west end of Lake Superior are of the same age. On the St. Croix, in Wisconsin, the rock is for the most part a laminated sandstone of various colors, and either soft or hard. Some portions are partly calcareous; and towards the top of the series true limestone layers are intercalated. *Green-sand like that of the Chalk formation* occurs in some of the beds on the Upper Mississippi. (Hall.)

The Potsdam beds of Texas occur in Burnet co., Texas, where they consist of sandstones covered by limestone. (B. F. Shumard.)

Beds of sandstone and conglomerate, according to Dr. Hayden, skirt the Black Hills of Dakota (lat. 43°–45° N., long. 103°–104° W.), overlying the Azoic and containing characteristic fossils. Dr. Hayden has also observed a similar sandstone and conglomerate in the Laramie Range of mountains, along the margins of the Big Horn Range (lat 43°, long. 107°), and along the Wind River Mountains. Those of the Big Horn Range afforded the usual Primordial fossils.

The Potsdam formation is 60 to 70 feet thick in St. Lawrence co., N.Y., diminishing in some places to 20 or 30 feet; in Warren and Essex cos., 100 feet; in the St. Lawrence valley, 300 to 600 feet; about 250 feet in Lake Superior; 700 feet, according to Owen, on the St. Croix, Wisconsin; 50 to 80 feet in the Black Hills, Dakota; 200 feet at the Big Horn Range; 500 feet in Burnet co., Texas.

On Lakes Superior and Huron, in the copper region, there is a great thickening of the Primordial strata, in connection with eruptions of trap. The rocks rise in some places to a height of 3000 or 4000 feet, and consist of these igneous rocks mingled with the sandstone and a scoria conglomerate. These beds are mostly of the Calciferous epoch. (J. D. Whitney.)

b. Region of the Appalachians.—Along the Appalachian chain the great thickness of the accumulations, and especially of the slates, is the striking peculiarity. At Highgate, near the northern boundary of Vermont, the rock is a red sandstone containing fossils. This sandstone extends north into Canada, occurring near Herrick's Mills, in the township of St. Armand. It also occurs west of Swanton, in Vermont, where it is interstratified with black shales which contain the peculiar fossils of the epoch, and some species are identical, according to Billings, with those found on the north side of the Straits of Belle Isle. At Snake and Buck Mountains, in Addison co., Vt., there are 700 feet of black shale overlaid by a thick bed of sandstone and magnesian limestone, all of the Potsdam epoch (Billings). At Georgia, Vt., there are black shales which have afforded some large trilobites. South of these regions, east of the Hudson River, along by the Taconic Mountains (2″, 2″ on map, p. 170), in the western

slope of the Green Mountain Range, the Potsdam epoch is supposed to include the lower shales, while the rest of the rocks may be of the Calciferous epoch.

In Pennsylvania there are 2000 feet of lower slates, overlaid by 90 feet of sandstone, and this by 200 to 1000 feet of upper slates (H. D. Rogers). In Virginia there are 1200 feet of lower slates, 300 of sandstone, and 700 of upper slates (W. B. Rogers). In eastern Tennessee Professor Safford has described, as of this age, the "Chilhowee" sandstones and shales, several thousand feet in thickness (consisting of sandy shales, sandstones, and light gray quartzite), resting on the Ocoee conglomerates, sandstones, and micaceous, talcose and chloritic slates.

c. Eastern border.—On the north side of the Straits of Belle Isle, north of Newfoundland, the Potsdam rocks are gray and reddish sandstone, 231 feet thick, overlaid by 141 feet of limestone, with some shale, and the latter contains fossils related to those of Georgia, Vt., while in the former there is the *Scolithus* of the New York beds:

2. Calciferous epoch.—*a. Interior Continental basin.*—In northern New York some of the layers of this Calciferous sandrock are very hard and siliceous, and contain geodes of quartz crystals, as at Diamond Rock, Lake George, and Middleville and elsewhere in Herkimer co., etc. The impure limestone layers are adapted for the production of hydraulic lime. The mixture of calcareous with hard siliceous characteristics is a striking peculiarity of the rock. Owing to the lime present, much of it becomes rough from weathering. Besides quartz and calcite, barytes, celestine, gypsum, and occasionally blende and anthracite, are found in its cavities.

In Michigan, south of Lake Superior, the Calciferous beds are arenaceous, as in New York, but with some magnesian limestone. Farther west and south the "magnesian limestone" of the epoch is an extensive formation; but it contains some intercalated sandstone, and in its lower layers are occasionally geodes of quartz or chert. On the Upper Mississippi, at the Falls of St. Anthony, and also in Iowa, Minnesota, and Wisconsin, the limestone is overlaid by the St. Peter's sandstone (Owen), a friable, incoherent, white rock, affording sand for glass-making. (Whitney.)

In Missouri there are—(1) a magnesian limestone (No. 1) overlaid by a sandstone (2), about 350 feet in thickness; (3) a second magnesian limestone, with some sandstone layers and chert, 500 to 600 feet thick; (4) a sandstone, often cherty and containing quartz crystals in cavities, 70 feet; (5) a third magnesian limestone, cherty and arenaceous, 150 feet; (6) another sandstone; (7) a fourth magnesian limestone. (Swallow.)

The thickness in Canada is about 150 feet; in New York State, 50 to 300 feet; in Michigan, on the Menomonee (Lake Superior region), 50 to 100 feet; in Wisconsin and Iowa, over 200 feet; in Missouri, between 500 and 1000 feet.

The magnesian limestones of the Calciferous epoch in the West form bold cliffs along the streams where they have been cut through by running water and other agencies. An analysis of the rock is given on p. 84. It is often oolitic.

b. Region of the Appalachians.—The Calciferous beds along the Appalachians have their greatest thickness to the north. At Point Levi, near Quebec, where they have been called the Quebec group, they have been estimated to be 5000

to 7000 feet thick (Logan). They consist of black and blue shales, gray sand stone, with some conglomerate, beds of magnesian and common limestone (some of them fossiliferous), slates containing graptolites, red and green shales of great thickness, and, at the top of the series, a sandstone 2000 feet thick, called the "Sillery" sandstone. Hunt has found some of the dolomitic conglomerate to consist largely of green-sand (*glauconite*).

The rocks east of the Hudson, called Taconic rocks by Professor Emmons (from the Taconic range lying along the western slope of the Green Mountains), have been referred to this epoch. (Hunt.) They consist of slates, quartz-rock, and limestone, and include the marble of western Massachusetts and Vermont. Fossils, probably of the Trenton period, occur in the Vermont limestone (see p. 391).

Professor Emmons long since pointed out that these rocks were older than the strata on the west side of the river, and, regarding them as pre-Silurian, has called them the Taconic system. He has estimated the thickness at 20,000 feet. The rocks dip at a large angle as the result of great dislocations and folds, and the true thickness is of difficult determination. It is probable that the thickness estimated for the Quebec group is nearer the true amount, as has been suggested by T. S. Hunt. The precise line between the Potsdam and Calciferous strata in this Taconic series has not been ascertained. Continuing along the Appalachians into Pennsylvania, we find the limestone strata predominating. H. D. Rogers estimates the sandstone or lower part at much less than 1000 feet, and the limestone portion at 1950 feet in the Kishicoquillas valley and 5400 feet in the Nittany valley.

In eastern Tennessee, also within the Appalachian chain, the earlier part of the epoch is represented by laminated sandstones, some hundreds of feet thick; above this, a magnesian limestone, often oolitic, estimated at 1000 feet in thickness, bluish below, grayish at the middle, and gray and cherty above.

The Calciferous rocks throughout the Appalachians have been greatly disturbed. The beds usually lie with their edges to the surface and dipping at a large angle.

c. Eastern border.—At the Mingan Islands, in the Gulf of St. Lawrence, the Calciferous sandrock occurs overlaid by a white limestone, which is probably referable to the same epoch. Upon the latter rests the Chazy limestone. The white limestone is fossiliferous, and none of the species are identical with known Chazy forms, while several occur in the sandrock below.

Structural peculiarities.—(*a.*) The thin lamination of most of the arenaceous beds is an important characteristic.

(*b.*) The layers of the Potsdam sandstone in New York, Canada, Michigan, Wisconsin, and elsewhere, are frequently made up of obliquely laminated layers, as in fig. 61 *e*, p. 93.

(*c.*) The layers in Michigan and elsewhere have sometimes the compound character illustrated in fig. 61 *f*. This figure (by Foster & Whitney) is from the Potsdam sandstone of Lake Superior.

(*d.*) Ripple-marks (fig. 62) are common on many of the layers of the Potsdam sandstone in New York, Canada, and the West, and also in sandstones of the Calciferous epoch in Missouri.

(*e.*) **Mud-cracks** (fig. 64) characterize the layers in many places.

(*f.*) **Wave-marks** (§ 101) occur on some of the layers.

(*g.*) Siliceous or cherty concretions, and geodes of quartz crystals, characterize many layers of the Calciferous epoch, both in New York and the West. Even the limestones of Missouri are cherty in some layers.

The above marks, *b* to *f*, are evidences, where they occur, either that the deposits were formed in shallow waters (*b*, *d*), or as emerged beaches or flats (*d*, *e*, *f*), or as wind-drifts over fields of sand (*c*).

3. **Minerals.**—The minerals of the Potsdam formations have already been partly enumerated. There are no important beds of ore in New York. Iron-ores occur in Canada. The *lead-bearing* rocks of Missouri and Arkansas are the magnesian limestones of the Calciferous epoch; and with the lead-ore (galena) occur also valuable ores of cobalt, and the associated species, pyrites, barytes, calc spar, etc. The copper-mines of the Lake Superior region are in the rocks of this period; and some remarks upon them will be found on page 195. Quartz crystals in great abundance occur in cavities in the Calciferous rocks of central New York, and fissures are often lined with crystals. Anthracite coal in small pieces is found in some of the Calciferous beds, and fragments are at times imbedded in the crystals of quartz, or lie loose in the cavities that afford the crystals.

2. European.

Rocks of the Primordial period have been observed in Great Britain, Scandinavia, Bohemia, and other countries.

In Great Britain they outcrop in the western half, and are most largely displayed in Shropshire. The rocks in this region are hard siliceous grits and sandstones, and often stand out in rude crags, as at the Stiper Stones; and they have in places ripple-marks, wave-marks, mud-cracks, and worm-burrows (*Scolithus*), like the Potsdam rocks of America. Their thickness is from 800 to 1000 feet. They are much inclined, and rest, according to Murchison, "in conformable apposition upon the upper edges of the Longmynd" rocks, or the Cambrian, as the latter are called (a name first used by Sedgwick). These Cambrian rocks are slates and sandstones, having the estimated thickness of 26,000 feet; and, although regarded by Murchison as sub-Silurian, three or four fossils have been detected in them,—viz.: two species of Sea-weed or Corallines (genus Oldhamia) at Bray Head, in Ireland; and burrows of worms, and a fragment of a Crustacean, in Shropshire. In North Wales there are

Lingula flags, like those of the New York and Western Potsdam. In northwest Scotland, beds referred to the Cambrian, consisting of red and purple sandstones and conglomerates, overlie unconformably the crystalline Azoic,—"the fundamental gneiss" (Murchison).

It should be here stated that Murchison places these Cambrian beds on the same horizon with the Huronian of Canada. The correctness of this inference is not yet fully established. A large portion of the crystalline rocks and schists of the Highlands of Scotland are metamorphic rocks of the Silurian age.

In Lapland, Norway, and Sweden, there is a Primordial sandstone overlaid by schists, the lowest beds passing at times into a conglomerate. They are the regions A, B of the geologist Angelin. In Bohemia, the lowest Primordial beds are schists 1200 feet thick, called by Barrande *Protozoic schists*, or the Primordial Zone, and numbered C in his series,—his A, B consisting of schists and conglomerates conformable to C. Until recently B was thought to contain no trace of life, and therefore to be below the Primordial; but within a short time worm-burrows have been reported by Dr. Fritsch to occur in some of these inferior beds. The formation C has been regarded as the equivalent of the Potsdam; but it may be necessary to add a part or all of B. Barrande's next division, lettered D, consisting of schists, sandstones, and conglomerates, corresponds to the rest of the Lower Silurian; but the lower portion of it may represent the Calciferous epoch.

II. Life.

1. American.

As the life of the Potsdam period is the beginning of the system of life deciphered in American geological history, great interest attaches to it.

1. *Plants.*

Algæ, or *Sea-weeds*, are the only plants distinguished; the species are related to the Fucoids, or leathery sea-weeds, of existing coasts (p. 167).

In general, the remains are stony, vermiform, branching fossils, wholly destitute of the original vegetable material. But in some places thin seams of mineral coal have been found beneath or near fucoidal layers; and in Herkimer co., N.Y., the quartz crystals sometimes contain fragments of anthracite. The lowest of these distinct *fucoidal* layers in New York occurs in the inferior part of the Calciferous beds: it abounds in slender branched but irregular stems, called *Palæophycus irregularis* H. (the name of the genus being from the Greek for *ancient Sea-weed* or *Fucus*). In another and higher layer, the stems are as

large as the finger; the species is the *P. tubularis*. A branched or palmate species is the *Buthotrephis antiqua* H. Other species of Palæophycus occur in the beds of the Calciferous epoch.

It is possible that the infusoria called Diatoms, now referred to the vegetable kingdom, existed in the waters, and along with Sponges they may have been a source of part of the chert and quartz in the beds. But no remains of these microscopic species have yet been detected in so ancient strata.

The cylindrical upright stems, called *Scolithus*, common in the Potsdam beds, are now regarded as the fillings of worm-holes.

2. *Animals.*

Among the animals of the Potsdam or Primordial period, though few in species, three of the sub-kingdoms were represented,—the Radiate, the Molluscan, and the Articulate.

The species are all marine; none are proved to be of fresh-water or terrestrial life. They included,—

1. Among *Protozoans:* probably Sponges (fig. 236 A) and Rhizopods.
2. Among *Radiates:* Crinoids, of the order of Echinoderms; Graptolites, supposed to be of the order of Acalephs; and possibly coral-making Polyps.
3. Among *Mollusks:* Bryozoans, Brachiopods,* Conchifers, Ptero-

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* As *Brachiopods* are the most abundant fossils of the Silurian, their distinguishing characteristics and the more important genera are here mentioned, —taken principally from Davidson (Palæontographical Society publications).

1. *Animal.*—As stated on page 158, the living animal, unlike all other Mollusks, has (1) a pair of spiral arms, as shown in figs. 212 and 215; and to this the name *Brachiopod* alludes, from the Greek for *arm* and *foot*. These arms may sometimes be thrown far out of the shell, so as to be used for taking food. (2) The animal, as well as shell, is symmetrical either side of a vertical line let fall from the centre of the hinge,—the line *a b* in fig. 213; and in this the species differ from all the Conchifers (or Lamellibranchs). (3) There are no branchiæ (gills) apart from the pallium or mantle: and hence Brachiopods are often called *Palliobranchs*.

2. *Shell.*—The characteristics of most importance are as follow:—

a. The large valve (see fig. 211 and others) is the ventral.

b. The form of the internal supports connected with the spiral arms varies much, and often they are wanting. The loop-form is seen in figs. 208, 209, 210; the spiral, in figs. 212, 215; the short process, in fig. 217; and they are wanting in figs. 220, 221.

c. The general form and exterior markings of the shell afford important characters; the nearly equal convexity of the two valves, or a medial depression on the ventral valve, with a corresponding elevation on the dorsal, figs. 211, 213.

d. The beak of the shell may be very large and full (figs. 211, 229), or very

pods, Gasteropods (p. 156), and Cephalopods (p. 155). Thus, all the grand divisions of Mollusks were represented. This cannot be said of any other of the four sub-kingdoms of animal life. Even at the

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small and little prominent (figs. 219, 220); may have an aperture or *foramen* at apex (figs. 160, 213, 214), or not.

e. The hinge-line may be straight, or not; as long as the greatest breadth of the shell (211, 219, 222), or shorter (217, 218).

f. The presence or not of a cardinal area (hinge-area); there is a large one in fig. 211, and none in fig. 228.

g. The presence or absence of a *deltidium*,—composed of one or two accessory pieces occupying a triangular opening under the beaks, as seen in fig. 214. Sometimes a similar opening at the middle of the hinge is partly or entirely closed by the growth of the shell, so as to leave a triangular prominence, called a pseudo-deltidium, as in *Cyrtia*, *Streptorhynchus*, etc.

h. The markings on the inner surface of the valves are of special importance, and particularly the muscular impressions usually situated near the medial line not far from the hinge: on the *dorsal* (or smaller) valve there are in the articulated genera two pairs (*a* and *a'* in figs. 217, 220, 224, 226), sometimes coalescing so as to be one pair, for the attachment of the *adductor* muscle (closing the shell): one is usually in advance of the other, but in figs. 220 and 223 they are side by side; on the *ventral* (or larger) valve there is a single impression on the medial line between two others (figs. 218, 224); the single impression is the insertion of the *adductor* muscle (*a*, figs. 218, 221, 224, 227), and the pair are the insertions of the *cardinal* muscle; the latter muscle terminates on the *dorsal* valve usually in a small process.

Families of Brachiopods.

Terebratula Family (figs. 160, 208–210).—Having arm-supports of the form of a loop attached to the smaller or dorsal valve, and a foramen at the apex of the beak. Shell-structure punctate.

Spirifer Family (figs. 211–215).—Having spiral supports; shell usually with a medial fold; hinge-line commonly long and straight (sometimes short); beak large and full.

Rhynchonella Family (figs. 216–218).—Having the arm-supports short curved processes; beak usually full, but narrow, and having a foramen; shell seldom wider than high.

Orthis Family (figs. 219–227).—Arm-supports wanting; shell rarely with a medial fold; shell varying between orbicular and D-shape; beak usually very small, but sometimes produced.

Productus Family (figs. 228–230).—Arm-supports wanting; shell without a medial fold, or almost wholly so; hinge-line straight, often as long as the breadth of the shell, or nearly so, and without a cardinal area, or with only a narrow one (excepting in *Strophalosia* and *Aulosteges*): surface often tubular-spinous; form usually D-shape, with the dorsal valve very concave; beak often very large and full.

Discina Family (figs. 233–235).—Thin and small disk-shaped shells; orbicular

close of the Silurian age the Radiate type—the lowest of the four—was less fully displayed in its subdivisions than the Molluscan.

4. Among *Articulates:* marine worms, and Crustaceans of the tribes of Trilobites (figs. 242, 243, 245) and Ostracoids (p. 154).

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or ovate; a slit or foramen through the ventral valve; no articulation between the valves.

Lingula Family (figs. 161 and 236).—Thin and small shells; orbicular or subovate: no foramen; no articulation.

Besides these there are also the *Crania* and *Thecidium* families.

GENERA OF BRACHIOPODS.—1. *Terebratula Family.*—Genus *Terebratula*, like figs. 160 and 208; the loop small, as in fig. 209. Genus *Waldheimia*, the same, the loop large, fig. 208.

Besides these genera, *Terebratulina* has the side (or "crural") processes near the base of the loop united (fig. 210). Another genus, *Terebratella*, has the sides of the

Figs. 208–215.

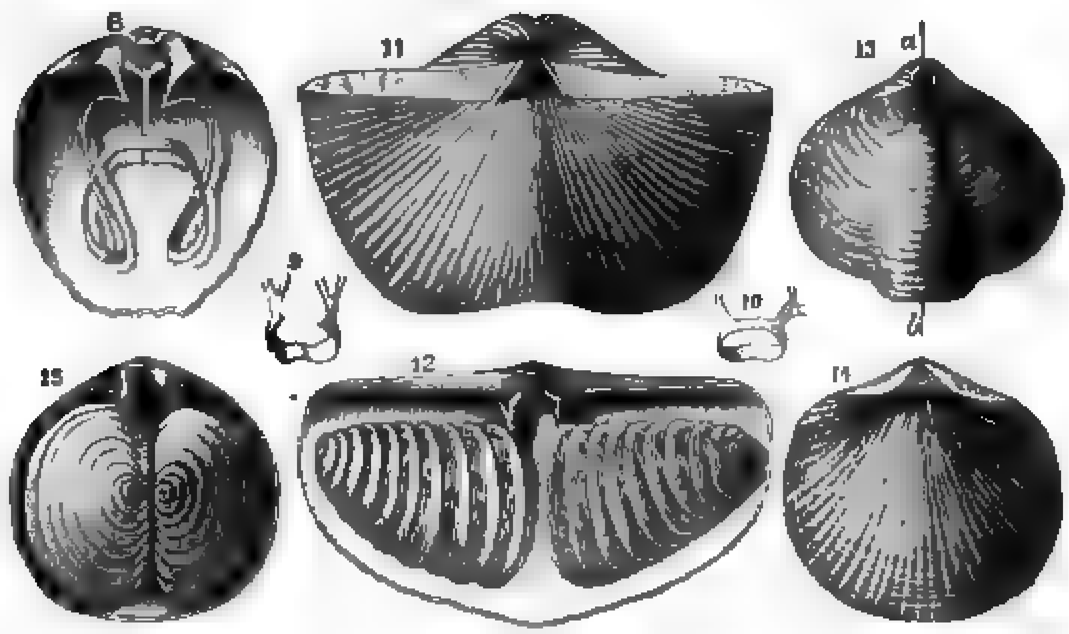

Fig. 208, Waldheimia flavescens; 209, loop of Terebratula vitrea; 210, id Terebratulina caput-serpentis; 211, Spirifer striatus; 212, same, interior of dorsal valve; 213, Athyris concentrica; 214, 215, Atrypa reticularis, the latter dorsal valve.

loop united at middle by a cross-piece, and this piece soldered to the shell. *Terebrirostra* has the beak extravagantly prolonged, so as to be longer than the dorsal valve. *Rensselaeria* has, instead of a loop, a peculiar hastate brachial support, projecting far within the dorsal valve. *Stricklandia* of Billings may be the same genus, and, if so, it antedates Rensselaeria. *Centronella* seems to be intermediate between *Terebratula* and *Waldheimia*. Other genera, rarely met with, are *Trigonosemus*, *Megerlia*, *Magas*, *Argiope*, appearing first in the Cretaceous, and *Kraussia*, *Bouchardia*, and *Morrisia*, known only in recent seas, with a possible exception of the last. *Stringocephalus* is another genus, probably constituting a sub-family, occurring in the Devonian.

The most abundant fossils in the Potsdam beds are the shells of the Brachiopod genus Lingula (figs. 237–239), and Trilobites.

The Lingulæ are so numerous in some places as to give their name to the rock: thus, there are the *Lingula grits* and *Lingula flags*,

2. *Spirifer Family.*—The genus *Spirifer* includes the common species, having usually a long hinge-line and distinct cardinal area (figs. 211, 212). In *Athyris* (fig. 213) the hinge-line is much shorter, the hinge-area small or none, the beak contracted and having a small round aperture. This genus is like *Terebratula* in its narrow form, and beak without cardinal area, but has the spires of the Spiri-

Figs. 216–227.

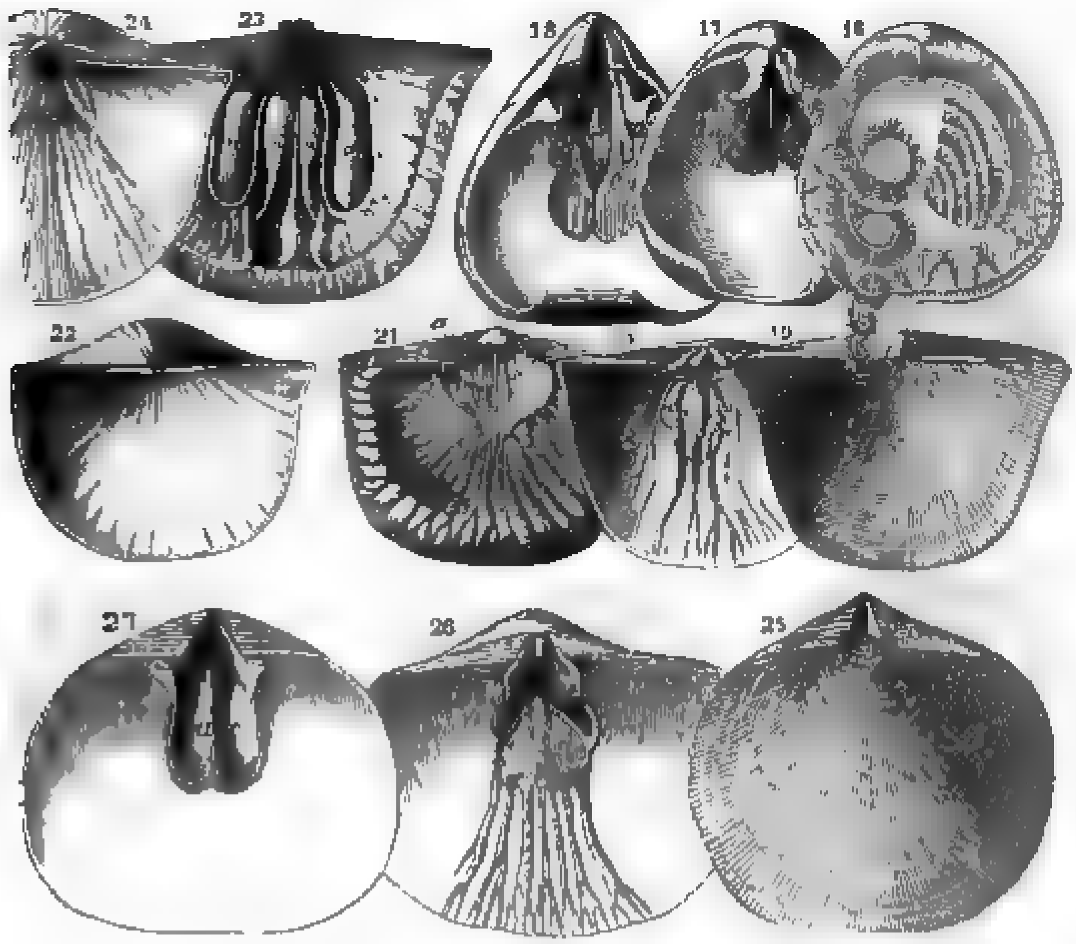

Fig. 216, Rhynchonella psittacea, showing the spiral arms of the animal; 217, id. dorsal valve; 218, id. ventral; 219, Strophomena planumbona: 220, id. dorsal valve, 221, id. ventral; 222, Leptæna transversalis; 223, id. dorsal valve; 224, id. ventral; 225, Orthis striatula; 226, id. dorsal valve; 227, id. ventral.

fers. *Atrypa* (figs. 214, 215) has the spires differently arranged, as in the figure; the form narrows to the beak, where there is no hinge-area or only a small one. *Uncites* has the beak extravagantly prolonged, and a large opening beneath it. *Cyrtia* has nearly the same extravagant prolongation of the beak, but with a large hinge-area, and a very small opening left at the top of the pseudo-deltidium.

among the Primordial strata; and the same is true of a closely-related shell of the genus Obolus (fig. 236). Besides Brachiopods of the Lingula family, there are others of the Orthis and Rhynchonella families even in the Potsdam epoch.

Koninckina is an imperfectly determined genus, resembling *Productus* in form, but differing internally.

Among other genera and subgenera of this family may be mentioned *Cyrtina*, *Retzia*, *Merista*, *Nucleospira*, *Trematospira*, *Rhynchospira*, *Charionella*, etc.

3. *Rhynchonella Family.*—The genus *Rhynchonella* (figs. 216–218) contains plump-ovoid or subtrigonal shells, usually narrower than high, and narrowing to the beak, having usually a foramen and no hinge-area; generally a U-shaped *flexure* in the anterior margin of the shell. *Pentamerus* has a much fuller and more incurved beak, and no area or deltidium, though there is a triangular

Figs. 228–236.

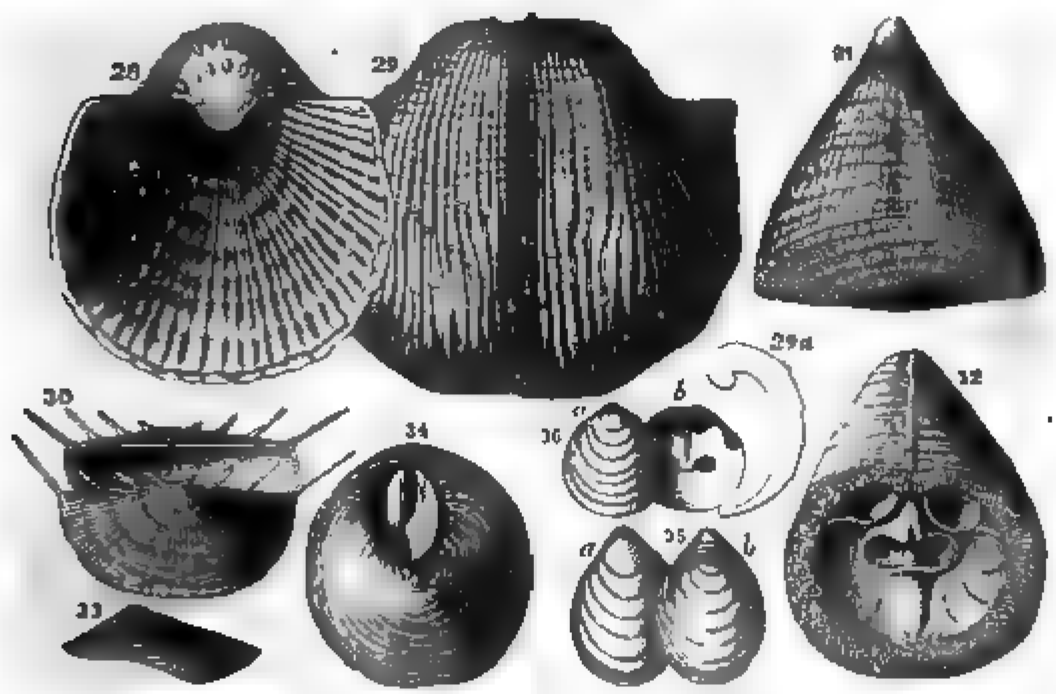

Fig. 228, Productus aculeatus, dorsal view; 229, Productus semireticulatus, ventral view, 229 *a*, section of Productus, showing the curvature of the valves, 230, Chonetes lata, opposite views; 231, Calceola sandalina; 232, Crania antiqua; 233, Discina lamellosa, side-view; 234, id. showing foramen; 235 *a*, *b*, Siphonotreta unguiculata, opposite views; 236, Obolus Apollinis.

opening at the middle of the hinge, which usually becomes closed in adult shells by the incurving of the beak. *Camarophoria* is a rare genus of the Carboniferous and Permian. *Porambonites*, a very plump shell of the Lower Silurian, near Rhynchonella. *Camerella* of Billings is another genus of this family, found in the Lower Silurian. *Leptocœlia* and *Eatonia* probably belong to this family.

4. *Orthis Family.*—In the genus *Orthis* (figures 225–227) the species are usually rather thin; often orbicular, at times a little wider than high; both

Trilobites were the largest animals of the seas, and the highest in rank. There were numerous kinds, and they varied in length from a sixth of an inch to two feet. Fig. 245 is a diminished representation of one of them: it is a species of Paradoxides (*P. Harlani*), from the Primordial rocks of Braintree, near Boston.

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valves in general nearly equally convex; the hinge-line usually not long, with a small cardinal area; a few species resemble a narrow Spirifer, and have a medial fold and long hinge-line. *Orthisina* has the hinge-area very large and reversed-triangular, with a convex deltidium, and the shell subquadrate. *Strophomena* contains thin D-shaped species (figs. 219–221), with a straight hinge-line about as long as the width of the shell, a very narrow hinge-area, the dorsal valve often very concave, with the ventral bending to correspond, and the four adductor muscular impressions in the same transverse line. *Leptæna* is similar (figs. 222–224), but has the four muscular impressions of different character, as seen in fig. 223, while in Strophomena they are as in fig. 220.

5. *Productus Family.*—In the genus *Productus* (figs. 228, 229) the beak is very full; hinge-line usually a little shorter than the width of shell; no true hinge-area, and no beak-aperture; the smaller valve concave; the surface of the shell spinous, the spines tubular. The margin of the shell is prolonged downward often to a great length, and sometimes closes around into a tube. *Chonetes* (fig. 230) has a straight hinge-line, commonly as long as the width of the shell, the form rather thin, with the beaks not full and prominent, resembling Leptæna; smaller valve concave; hinge-edge of larger valve furnished with a few spines. *Strophalosia* is much like Productus in form and spines, but is more circular, and the shells have a hinge-area, and a regular hinge with teeth; it also differs in being attached by the beak of the ventral valve. *Aulosteges* is also similar to Productus in general form and spines, but there is a broad triangular hinge-area, and the beak is twisted somewhat to one side.

6. *Discina Family.*—In *Discina* (figs. 233, 234) the form is orbicular or oval and the valves low-conical; there is a slit through the ventral valve, beginning at or near the highest point. The genus *Orbicula* is here included. *Trematis* is similar, but one valve has the umbo or prominent point marginal, or the slit reaches nearly to the margin. In *Siphonotreta* (fig. 235) the form is ovate, the beak projects at the margin, is somewhat pointed, and has a small aperture. *Acrotreta* has the perforate valve elevated into a high oblique cone.

7. *Lingula Family.*—*Lingula* (fig. 161) is narrower than high, and pointed at the beak; valves equal, thin. *Obolus* (fig. 236) is rotund or rotund-ovate; valves a little unequal, the dorsal valve being the smaller and least convex, as in most Brachiopods; muscular impressions, six,—two medial, two lateral, and two very near the umbos (fig. 236 *b*),—having some approximation to the *Craniæ*. *Obolella* Billings has still different muscular impressions, as shown in fig. 244 A.

8. *Crania Family.*—The genus *Crania* has internal markings, as in fig. 232, and the shell was attached when living by the substance of one valve to a rock or other support. *Calceola* (of doubtful relations) is like a cone flattened on one side and closed with a lid, as in fig. 231; valves not hinged.

9. *Thecidium Family.*—*Thecidium* contains thick-shelled species, higher than

Besides these remains of Crustaceans, there are peculiar tracks, found at Beauharnois and elsewhere in Canada, and called *Protichnites* (fig. 245 B), which are supposed to have been made by large Crustaceans having stout legs like the modern Limulus: they are anomalous in form, and need further explanation. A very different kind of track, also first made known by Logan (fig. 245 A), occurs in the same Canada rocks. It is six and three-quarter inches wide; and one trail is continuous for thirteen feet. It has been regarded as the track of a very large Gasteropod; but it is quite as probable that it was made by the clusters of foliaceous appendages of one of the great Trilobites,—these appendages being its locomotive organs.

Impressions of long marine worms have been reported from some of the shales. Besides these, there are worm-holes in the Potsdam sandstones—though now filled with rock—which are referred to burrowing worms of the *Arenicola* family (so called from the Latin *arena, sand,* and *incola, inhabitant*). They penetrate the rock vertically, and are often in pairs, as is now the habit of such worms. The most common kind in the Potsdam sandstone is called *Scolithus linearis* (fig. 240); and for a long time it was supposed to be the remains of a fucoidal plant. They are so abundant in these deposits of the Potsdam epoch that they serve to identify them in different regions.

In the North American rocks of the Potsdam period, already nearly sixty species of Trilobites have been found and described, and over forty species of Graptolites. Although the species of shells were not numerous, some kinds were exceedingly abundant, and many layers are almost wholly composed of them.

If the Potsdam and Calciferous epochs were named from their most characteristic species, the former would be the Lingula or Paradoxides epoch, and the latter the Graptolite.

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wide, having a pointed beak, very large triangular hinge-area, and internally digitate muscular impressions; commenced in the Trias, and has a single living species.

Davidsonia is a genus of rare occurrence and undetermined relations. There is some resemblance to *Leptæna;* but it has a pair of low and faint spiral cones on the inner surface of the larger valve.

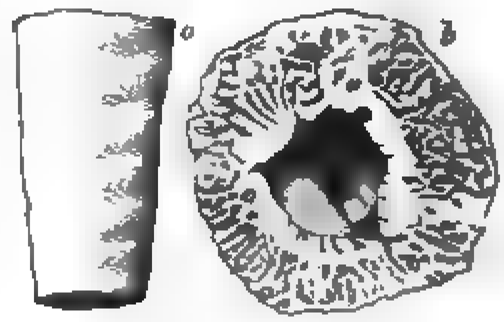
The following genera have species in the existing seas; and those having an asterisk are known only recent. In the *Terebratula family,* the genera Terebratula, Waldheimia, Terebratella, Megerlia, Kraussia,* Bouchardia,* Morrisia, Argiope; in the *Thecidium family,* Thecidium; in the *Rhynchonella family,* Rhynchonella; in the *Crania family,* Crania; in the *Discina family,* Discina; in the *Lingula family,* Lingula. There are no living species of the *Orthis, Productus,* and *Spirifer* families.

The genera *Lingula* and *Discina* are the only two in the animal kingdom, as far as now known, that began with the primal life of the globe, in the Potsdam epoch, and continued on, in a succession of species, to the present time,—the species changing, but not the genera. The analyses of the ancient and modern shells by T. S. Hunt confirm the fact of the family identity between the ancient and modern species (p. 68). Unlike nearly all other shells, they have the constitution of bones, or are mainly phosphate of lime. Another genus,—*Nautilus*,—if the specimens are rightly referred, commenced in the Calciferous epoch, and still has living representatives, nearly equalling the *Lingula* in the length of its history.

Characteristic Species.—1. *Potsdam Epoch.*

Protozoans. — *Sponges.* — Fig. 236 A, *Archeocyathus Atlanticus* B., is either a coral or a sponge (Billings): *a* represents the external form, diminished one-half in size; *b*, a polished transverse section (natural size), showing an irregularity of structure more like that of a sponge than a coral. It comes from the north shore of the Straits of Belle Isle. *A. Minganensis* B. is another species from the same locality.

Fig. 236 A.

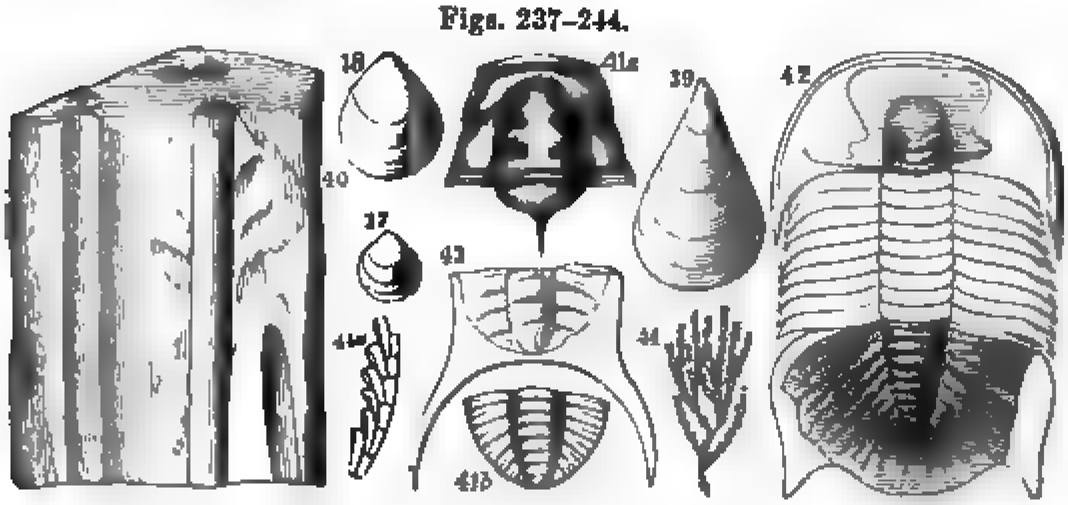


Archeocyathus Atlanticus.

Radiates. — *a. Polyps.* — No corals have been found in this formation, unless the Archeocyathus be of this nature.

b. Acalephs.—Fig. 244, *Graptolithus Hallianus* Prout, from St. Croix, Minnesota. For an explanation of the nature of Graptolites, see beyond, on page 190. Fig. 244 *a* is an enlarged view of a branch.

Figs. 237–244.



Figs. 237, 238, Lingula prima; 239, L. antiqua, 240, Scolithus linearis; 241 *a*, *b*, Conocephalus minutus, head and tail shields (×4). 242, Dicellocephalus Minnesotensis (×½); 243, D. Iowensis; 244, *a*, Graptolithus Hallianus.

c. Echinoderms.—Stems of Crinoids, made up of a series of disks, have been found at La Grange, Minnesota (D. D. Owen). They were probably Cystidean. An impression of a single disk has been observed on the sandstone of Keeseville, N.Y.

Mollusks.—*a. Bryozoans.*—No Bryozoans are known of this period, unless some of the Graptolites may be of this nature. (See p. 190.)

b. Brachiopods.—Fig. 237, *Lingula prima* Conrad, from Keeseville, N.Y.; 238, same, from Lake Superior (Tequamenon Bay), and from St. Croix, Wis.; 239, *L. antiqua* H., from St. Croix,—a much larger specimen than those of New York. Other species of Lingulæ have been described from the rocks of Wisconsin and Canada. *Obolus Apollinis*, fig. 236, or a related species, occurs near the mouth of Black River in Iowa (D. D. Owen). *Obolus Labradoricus* Billings, is a species from the north shore of the Straits of Belle Isle. *Obolella* Billings, is the name of a related genus of which two species are from the Straits of Belle Isle, one from Troy, N.Y., one from Wisconsin, and one (fig. 244 A) from the Black Hills of Dakota. The genus *Discina*, or *Orbicula* (figs. 233, 234), begins in this epoch, and a species is reported by D. D. Owen from the Wisconsin beds, and

Fig. 244 A.

Obolella nana.

Fig. 244 B.

Theca gregarea.

another, by B. F. Shumard, from Texas. *Orthisina festinata* B., *Camerella antiquata* B., are other Potsdam species of Brachiopods.

c. Conchifers.—None are known.

d. Pteropods.—Fig. 244 B, *Theca* (*Pugiunculus*) *gregarea* M. & H., from the Big Horn Mountains, lat 43° N., long. 107° W., where they are crowded together in great numbers on the slabs. *Theca primordialis* H., from Trempaleau, Wisconsin, and Chippewa River. A Theca has also been found at Keeseville, N.Y. *Salterella rugosa* B., and *S. pulchella* B., from the north shore of the Straits of Belle Isle, may be Pteropods.

e. Gasteropods.—Imperfect specimens resembling a *Pleurotomaria* and the *Ophileta compacta* have been observed in Canada, and the former also at Keeseville, N.Y. A Gasteropod of the form of a *Capulus* occurs in Texas (B. F. Shumard).

f. Cephalopods.—Two species of Orthoceras occur in the Potsdam of Canada, in the uppermost layers, along with great numbers of *Lingula antiqua* (or *acuminata*). This discovery by Logan places the Cephalopods lower than they were before known to occur.

Articulates.—*a. Worms.*—Fig. 240, casts of worm-holes of *Scolithus linearis* H. The *Fucoides ? duplex* H. (Foster & Whitney's Lake Superior Report, pl. 23) probably belongs to another species of worm.

b. Crustaceans.—(1.) *Phyllopods.*—No Phyllopods have been found in the American beds, although they occur in the Primordial rocks of Great Britain.

—(2.) *Trilobites.**—Fig. 241, *Conocephalus minutus* Bradley, from Keeseville, N.Y.: *a*, the head-shield or buckler, with the side-pieces wanting, none having

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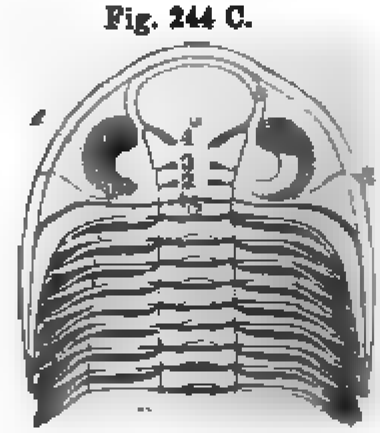
* The genera of Trilobites are distinguished mainly by the form and markings of the head and tail portions of the body, and the eyes. The large anterior segment is the head or buckler; the posterior, when shield-shaped and combining two or more segments, the *pygidium*. The middle area of the head, which is often very convex, is the *glabella*; the parts of the head either side of the glabella, the *cheeks*; a suture running from the anterior side of the eye forward or outward, and from the posterior side of the eye outward (*e e* in the figure), the *facial suture*; a prominent piece on the under surface of the head, covering the mouth, the *hypostome*. The eyes may be very large, as in *Dalmania* (fig. 244 C), *Phacops*, and *Asaphus* (fig. 320), or small, as in *Homalonotus*; or not at all projecting, as in *Trinucleus* (fig. 323); and may also differ in position in different genera.

Fig. 244 C.



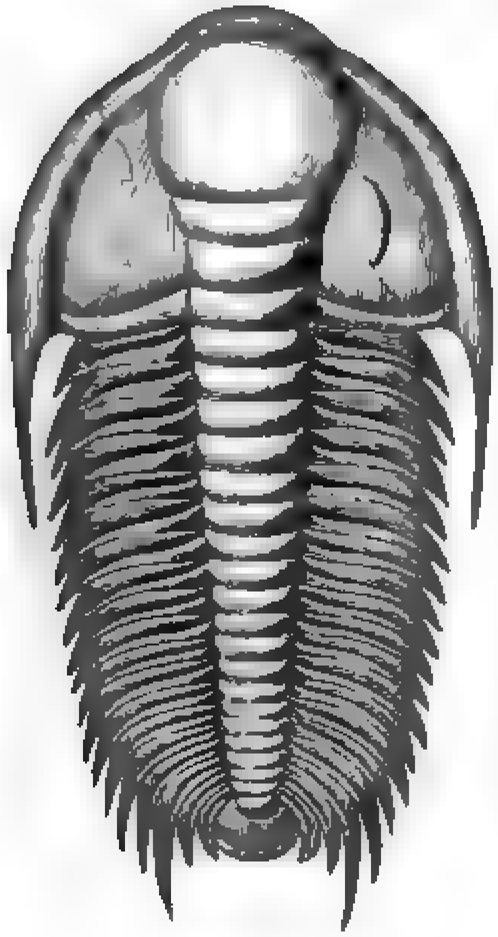
Dalmania Hausmanni.

The glabella may be broader *anteriorly*, as in *Phacops*, *Dalmania*, *Trinucleus*; or broader *posteriorly*, as in *Calymene* (fig. 321), *Bathyurus* (fig. 261); and it may vary otherwise in form; or it may be ill defined, as in *Isotelus* (fig. 320) and *Illænus* (fig. 333). It may have no furrows across its surface, or one or more up to four (or rarely five). The four may be numbered, beginning behind, No. 1, 2, 3, 4 (fig 244 C). These furrows may extend entirely across, or be divided at middle as Nos. 2, 3, 4 in fig. 244 C. *Isotelus* (fig. 320) and *Illænus* (fig. 333) have none of these furrows; *Trinucleus* (fig. 323) has No. 1 faint or obsolete; *Asaphus* (fig. 332), *Homalonotus*, and *Bathyurus* have No. 1 entire; *Dicellocephalus* (fig. 242) has Nos. 1 and 2 entire, and 3 divided; *Calymene* (figs. 177, 242), *Dalmania*, *Cryphens*, *Ogygia*, *Cheirurus*, *Proëtus*, have No. 1 entire and 2, 3, 4 divided, but 4 is sometimes obsolete. *Sao* (fig. 261 A) has No. 1 entire and 2, 3, 4 divided, but there is a medial longitudinal depression in which 2, 3, 4 from either side coalesce. In one group, the genus *Lichas*, the glabella has, on either side, one or two longitudinal or oblique lobes (figs. 322, 409). The furrows, as shown in the genus Paradoxides, correspond to articulations of the body. They are mostly obliterated in the higher Trilobites where the head-shield is most compact, and are most distinct in the lowest, like Paradoxides, being a part of that general looseness of body that marks inferior grade.

The position of the facial suture (see p. 154 and *e e* in fig. 244 C) affords characters for distinguishing genera; also the number of segments of the body (in *Agnostus* the number is very small, and the head and pygidium are almost in contact); the continuation of the free movable segments to the posterior extremity, or the union of the posterior into a shield (called the pygidium); in some cases the breadth of the middle lobe of the body as compared with the lateral, it being very broad in *Homalonotus* (fig. 410), the form of the fold of the shell beneath the head at its anterior margin; the shape of the hypostome; the capability of folding into a ball by bringing the abdomen to the head, as in *Calymene*, *Isotelus*, *Phacops*.

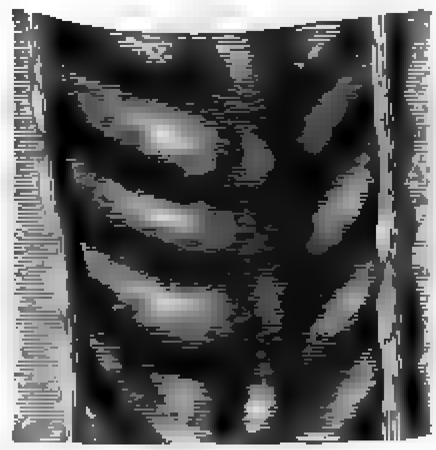
been found united to the head; *b*, the pygidium. Other species of this Primordial genus occur in northern Vermont, Labrador (Straits of Belle Isle), and Texas. Fig. 242, *Dicellocephalus Minnesotensis* D. D. Owen, a trilobite six inches long, from Lake St. Croix, Minnesota; fig. 243, *D. Iowensis*, pygidium, natural size, from near the mouth of Black River, Iowa. The name of this

Fig. 245.



Paradoxides Harlani (× ½).

Fig. 245 A.



Track of a Trilobite (× ⅙).

Fig. 245 B.

Protichnites 7-notatus (× ⅙).

genus is from *δικελλη, a shovel*, and *κεφαλη, head*. Fig. 245, *Paradoxides Harlani*, reduced, from Braintree, near Boston. *P. Vermontana* and *P. Thompsoni* are species from Georgia, Vt., and the Straits of Belle Isle; the latter is over four inches long. *P. Bennetii* is a large species from Newfoundland. *Bathyurus parvulus* and *B. senectus* B. are from the Straits of Belle Isle. *Peltura holopyga* is another trilobite, three and a quarter inches long, from Georgia, Vt. Species of *Agnostus*, *Arionellus*, and *Dicellocephalus*, besides *Conocephalus*, occur in Texas. *Arionellus? Oweni* M. & H. is from the Black Hills, Dakota, and the Big Horn Mountains. *Paradoxides asaphoides* Emmons, is a large species from the Taconic slates of Washington co., N.Y.; and *Microdiscus quadricostatus* Emmons, a small trilobite, from Augusta co., Va., remarkable for a very narrow glabella as long as the head, and a short body. Fig. 245 A, section (referred to on p. 185) of a track, probably of a large trilobite, from near Perth, Canada, described by Logan, who names it *Climactichnites Wilsoni*. Fig. 245 B, track, supposed to be Crustacean (p. 185), called *Protichnites 7-notatus*.

2. *Calciferous Epoch.*

The great magnesian limestones of this epoch in the Mississippi valley rarely contain a fossil, and only a few species occur in the Calciferous beds of New York. Species are, however, numerous in some of the limestone layers of the Quebec group, and already 137 have been described from these strata.

Protozoans.—*Sponges?*—*Archeocyathus Minganensis* B. occurs at the Mingan Islands, in the lower part of the Calciferous.

Radiates.—*a. Polyps.*—No Polyp-corals have been found, unless the Archeocyathus belongs to this group. The genus *Stenopora* is represented among the Canada beds and at the Mingan Islands, and a doubtful coral from Phillipsburgh is referred by Billings to *Tetradium*. But both are probably genera of Acaleph-corals,—that is, the stony secretions of Hydroid Acalephs (see p. 162). The square form and four rays of the cells of Tetradium suggest this reference for that genus; and it is required for Stenopora by the minute size of the cells as well as the relation of the corals to the tabulate Favosites and Pocillopora.

b. Acalephs.—Graptolites* are common in the shales of this epoch, and 42 Canada species have been described by Hall. Figs. 246–248 represent the *Graptolithus Logani* H. from Canada, showing the centre of a group and the furcating mode of branching. They are supposed by Hall to have been spread

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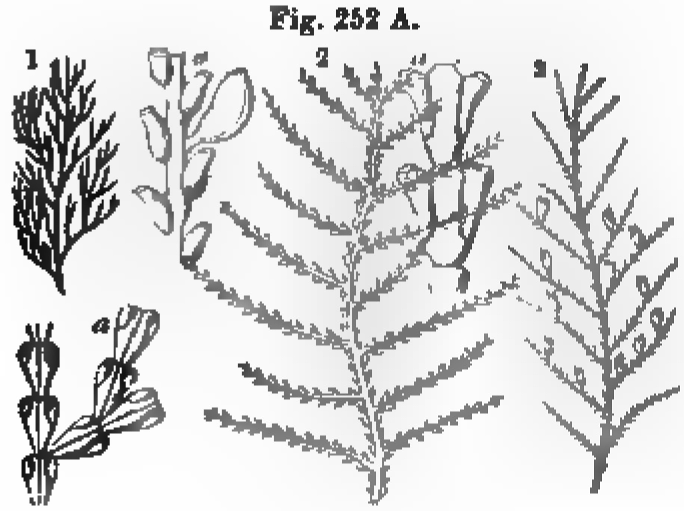
* The annexed figures illustrate the relations of the Graptolites to living species of animals. The fossils are never calcareous; the texture is membranous or a little horny, and usually only faint impressions are left in the rocks. No. 1 represents one of the branching Bryozoans, the *Notamia loricata*, and 1 *a* the

Fig. 252 A.

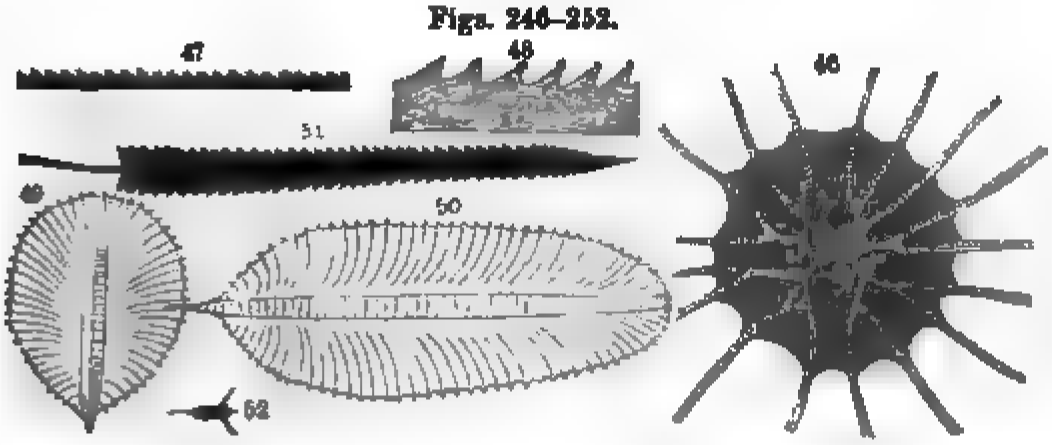


same enlarged. No. 2 is the *Sertularia abietina*, and 2 *a* the same enlarged. Along the branches there are capsules containing bulbs for reproduction; the bulbs pass out from the capsule when mature. No. 3 represents another species, the *Sertularia rosacea*, and 3 *a* the same enlarged; 2 *a* has one of the bulb-bearing capsules.

The prominent distinction in the corallum of the Bryozoans and Sertularians is that in the former the cells have no internal tubular connection, while in the latter the axis of the stem is tubular, and all of the cells communicate with one

out over the bottom and fixed in the mud only at centre. They probably grow at considerable depths. In fig. 246, which exhibits the centre of a branch-

Figs. 246–252.



Figs. 246, 247, 248, Graptolithus Logani, 249, 250, Phyllograptus Typus; 251, Graptolithus pristis; 252, young of Graptolite.

ing group, as figured by Hall, a membrane unites the branches at base; 247, a portion of a branchlet; 248, same, enlarged. The delicate notching along the margin is made by the cells of the several animals of the group. Figs. 249 and 250 are a leaf-shaped kind, the type of the genus *Phyllograptus* (the *P. Typus* H.). [Fig. 251 is a species from New York, the *G. pristis* H., from the shales of the Hudson River period.] Fig. 252 is regarded by Hall as a young Graptolite, from the Canada graptolitic shales. Numerous such forms were found among the impressions of Graptolites.

c. Echinoderms.—Crinoidal remains are not common. Among them Billings has distinguished some stems that probably belong to the genus *Glyptocrinus* (see fig. 339 for a species of this genus), and a fragment of the head of a Cystidean near *Palæocystites tenuiradiatus* H. of the next, or Chazy, epoch. There are fragments of several other species.

Mollusks.—*a. Bryozoans.*—A *Stromatopora* (a massive coral consisting of thin layers that are made up of minute cells, a species of which is common in the Trenton period) has been found at Phillipsburgh, Canada (Billings).

b. Brachiopods.—The Lingula family is no longer the most prominent among Brachiopods: the Orthis family takes precedence. Along with it occur species of the Rhynchonella family, as in the Potsdam.

Fig. 253, *Orthis* (*Orthisina?*) *grandæva* B. Other Brachiopods are *Lingula acuminata* Con., *Orthis parva?* Pander, *Camerella calcifera* B., a species of *Leptæna*, and of *Strophomena*.

c. Conchifers.—The first of this group yet reported is the *Conocardium Blumenbachii* B., found at the Mingan Islands in the White limestone (p. 176), a shell

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another and with the tubular axis. In the fossilized specimens it is often difficult, as would be inferred from the above figures, to determine which is the fact; and hence there are some doubts as to the relations of the Graptolites. It is quite possible that, while most of the so-called Graptolites are Sertularian (that is, Acalephs), some are Bryozoan (or Mollusks).

related to Cardium, and belonging to the division of Conchifers having a siphonal tube. This division, the sinupallial, was far less common in the Silurian

Figs. 253–260.

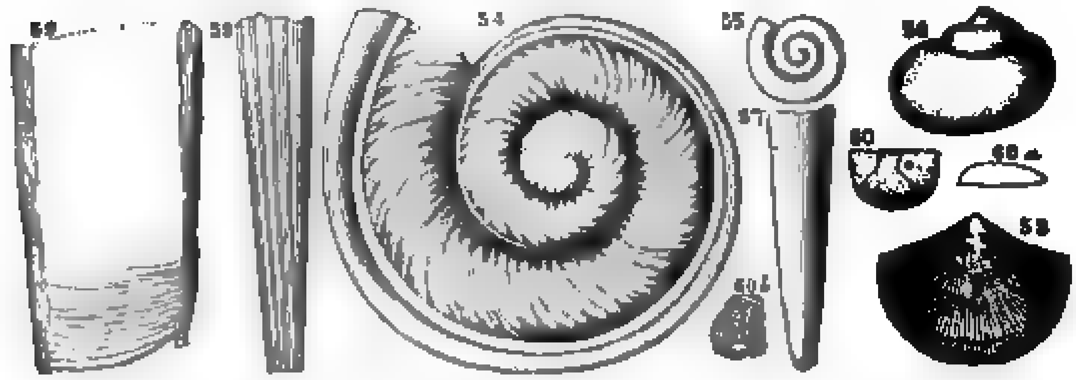


Fig. 253, Orthis (Orthisina?) grandæva; 254, Helicotoma uniangulata; 255, Ophileta levata; 256, Holopea dilucula; 257, 259, Orthoceras primigenium; 258, O. laqueatum; 260, 260 *a*, Leperditia Anna; 260 *b*, same, natural size.

than the integripallial, or that in which the tube was wanting; and it is therefore the more remarkable that the species first made known should have this high characteristic. Mr. Billings remarks that there are indications on the shell of the existence of the siphon (see p. 157). For illustrations of the genus, see figs. 331 and 457.

d. Gasteropods.—Many genera of Gasteropods are represented in the Calciferous rocks, and in all the aperture of the shell is without a beak (see p. 156). These genera are in part of the Trochus family.

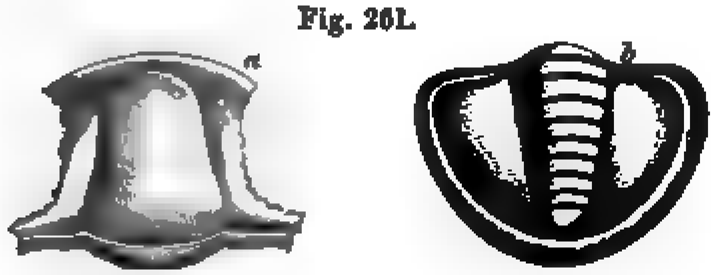
The following are characteristic species.—Fig. 254, *Helicotoma* (*Euomphalus* formerly) *uniangulata* H.; 255, *Ophileta levata* V.; *O. complanata* V.; *O. compacta*, a fine species from Canada, one and a half inches across; 256, *Holopea dilucula*; *Pleurotomaria Calcifera* B., from near Beauharnois, Canada; *P. gregaria* B., from St. Ann's, Canada, extremely abundant; *Maclurea matutina* H., from New York and Canada; *Murchisonia Anna* B. (a long turreted shell, approaching the *M. bellicincta*, fig. 306), from St. Ann's, on the island of Montreal, and also the Mingan Islands, in the White limestone and the sandrock below; *Ecculiomphalus Canadensis* B. (a shell three inches long, having the form of a curved horn without transverse partitions within); *E. intortus* B., a smaller species.

e. Cephalopods.—This highest tribe of Mollusks is well represented, though less abundantly so than in the next period. The chambered shells of these species in this period are either straight or nearly so, like a long, tapering horn, as in *Orthoceras* (whence the name, from the Greek ὀρθός, *straight*, and κέρας, *horn*); or arched or partially coiled, as in *Lituites*; or completely coiled, as in *Nautilus*. Figs. 257, 259, *Orthoceras primigenium* V., a species having the septa or partitions very closely crowded: 258, *O. laqueatum* H. Other species are *O. Lamarcki*; *Lituites Farnsworthi* B., a large species partially coiled and nearly five inches in its longer diameter; *L. imperator* B., a still larger species, 10½ inches across, having the first three whorls coiled in contact. These Lituites are from the upper part of the Calciferous sandrock of Phillipsburgh, Canada East. They appear to be among the largest of the Cephalopods, and, along with the Nautilus, the highest species of Mollusk in the Potsdam period.

Articulates.—*Crustaceans: Trilobites.*—Over forty American species of Trilobites of the Calciferous epoch have been described. They belong to the following genera:—Dicellocephalus, Bathyurus, Arionellus, Menocephalus, Conocephalus, Amphion, Agnostus, Cheirurus, and Asaphus. They are for the most part the same that characterize the Potsdam, but the genus Paradoxides is wanting, Dicellocephalus and Bathyurus are more numerous in species, and Agnostus, Cheirurus, and Asaphus are new additions to the tribe. Asaphus and Cheirurus have their fuller development later in the Silurian.

Fig. 261 represents the *Bathyurus Saffordi* B., a common species; *a*, the glabella, *b*, the pygidium. Some of the other species are *Agnostus Americanus* B.

Fig. 261.



Bathyurus Saffordi.

(Fig. 259 A represents a foreign species of this genus), *A. Canadensis, Dicellocephalus magnificus* B., a species eight or nine inches long, *Arionellus cylindricus* B., *Bathyurus capax* B., *Cheirurus Apollo* B., *Asaphus illænoides* B., all of which occur in the Quebec group, which has afforded in all thirty-six species of Trilobites. Phillipsburgh, C.E., and the Mingan Islands have afforded other species of the genera Bathyurus, Amphion, Asaphus, and Menocephalus.

Ostracoids.—Besides Trilobites, there are the earliest of the bivalve Crustaceans,—very small species having the body enclosed in a bivalve shell somewhat like a clam-shell, whence the name *Ostracoid*. Fig. 260, *Leperditia Anna*, from St. Ann's, Canada, side-view; 260 *a*, same, in profile; 260 *b*, a group of the same in the rock, natural size.

3. *Species of Wide Range.*

The following species continue from the Potsdam epoch into the Calciferous: —*Lingula acuminata, Ophileta compacta, Archeocyathus Minganensis.*

According to the latest investigations, the Calciferous and Chazy epochs are wholly distinct in life. The *Orthoceras laqueatum* (fig. 258), referred to the Calciferous, is suspected to be exclusively a Chazy species; the specimen from which it was described as Calciferous was of uncertain locality.

2. European.

The Primordial life of Europe was quite similar to that of America. The rocks contain sea-weeds (Fucoids) allied to Palæophycus. The lower sandstones are penetrated by the burrows of sea-worms (Scolithus). Graptolites occur in Sweden in the upper slates; and the shells of Lingulæ are in so great numbers as to give the name

of Lingula flags to some of the beds. Trilobites are the prominent life of the period.

Characteristic Species.

Sea-weeds.—Besides the Fucoids, there are two species of Oldhamia found in the Cambrian rocks of Ireland,—fig. 256 A, *Oldhamia antiqua;* 257 A, *O. radiata.* They were supposed by Forbes to be Bryozoan, but are generally regarded as Sea-weeds or Corallines.

Figs. 256 A–262 A.

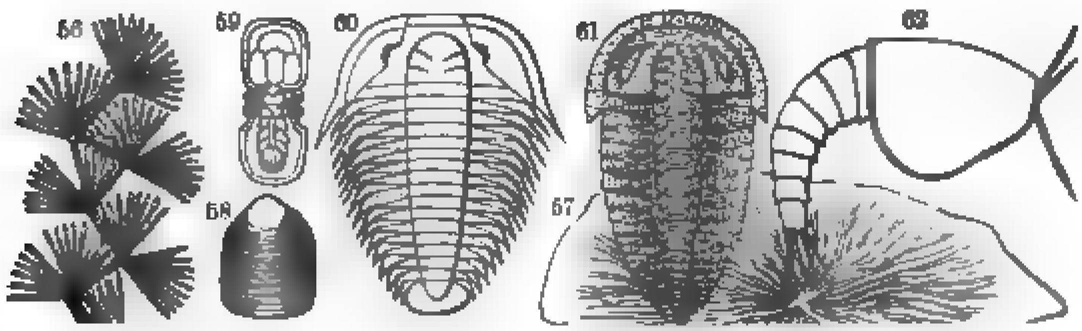


Fig. 256 A, Oldhamia antiqua; 257 A, O. radiata; 258 A, Lingula Davisii; 259 A, Agnostus Rex; 260 A, Olenus micrurus; 261 A, Sao hirsuta (× ½); 262 A, Hymenocaris vermicauda (× ½).

Radiates.—Of *Polyps*, none; of *Acalephs*, Graptolites; of *Echinoderms*, a few species of Crinoids of the family of Cystids; occurring in Bohemia.

Mollusks.—*Brachiopods.*—A few species of the *Lingula* and *Orthis* family. Fig. 258 A, *Lingula Davisii* of the Lingula flags of North Wales. *Conchifers.*—One species is reported as occurring in Great Britain. *Pteropods.*—There are a number of species of *Theca* in Bohemia, Sweden, and England.

Articulates.—*Trilobites* are more numerous in species than any other group. Over seventy have been found in Scandinavia, and nearly thirty in Bohemia. The common genera are *Paradoxides*, *Agnostus*, *Olenus*, *Conocephalus*, *Ellipsocephalus*, and *Sao*. Fig 259 A, *Agnostus Rex*, from Skrey, in Bohemia; fig. 260 A, *Olenus micrurus* Salter, from the Lingula flags of North Wales; fig. 261 A, *Sao hirsuta*, of Bohemia.

Phyllopods appear first in this period, occurring fossil in the Primordial rocks of Great Britain. Fig. 262 A is the *Hymenocaris vermicauda*, from North Wales. It is like a shrimp in form, but has no projecting movable eyes. Moreover, in place of ordinary legs, if a true Phyllopod, it had foliaceous appendages, which were too delicate to be preserved (whence the name, from φύλλον, *leaf*, and πούς, *foot*). The existence of such Crustaceans at the present day, and the absence in the fossils of feet and of pedicellate eyes, are evidence that the species are of this type.

III. Igneous Action and Disturbances.

Through New York and the greater part of the West no evidences of disturbance have been observed that can be traced to the Potsdam period. The rocks are for the most part nearly horizontal

and in general little altered, and the tilting which is observed appears to have taken place in a later period. These remarks apply to the larger part of the Potsdam rocks about Lake Superior. But on Keweenaw Point, the famous copper-region of Lake Superior, the sandstones of this period are associated with trap,—an igneous rock that was ejected through fissures opened in the earth's crust; and these trap ejections have added vastly to the accumulation, so that in some places about Keweenaw Point the alternations of sandstone, conglomerate, and trap rocks make a thickness of three or four thousand feet. Some of the conglomerate (according to Foster & Whitney, and Owen) seems to be made of volcanic scoria, like the tufa of modern volcanoes, as if the ejections were submarine and the cool waters had shattered the hot rock to fragments and so made the material of the conglomerate; and, as many of the masses are not rounded, these authors infer that it was piled up rapidly during the igneous action. Dr. D. D. Owen represents the trap as often in layers alternating with shale and other rocks, indicating eruptions at different times. The trap rocks of Lake Superior present many scenes of basaltic columns of remarkable grandeur. Some of them are represented and described in the Geological Report on Wisconsin, Iowa, and Minnesota, by Dr. Owen.

The native copper of the Lake Superior region is intimately connected in origin with the history of the trap and sandstone. The copper occurs in irregular veins in both of these rocks near their junction; and whenever the trap was thrown out as a melted rock, the copper probably came up, having apparently been derived from copper-ores in some inferior Azoic rocks through which the liquid trap passed on its way upward. The extent to which the rock and its cavities are penetrated and filled with copper shows that the metal must have been introduced by some process before the rock had cooled. The nature of this process, and the condition of the metal (whether as a salt or other compound in solution, or in vapor), have not yet been ascertained. One great sheet of copper which has been opened to view in the course of the mining was forty feet long, and weighed, by estimate, two hundred tons. The copper is mixed with native silver; and some specimens are spotted white with the more precious metal.

In addition to copper, the rocks contain the usual trap minerals, —zeolites, datholite, calcite, quartz; and some calcite, datholite, and analcime crystals were formed about threads of copper.

Besides the disturbance connected with the Lake Superior rocks, there were great oscillations of level over the continental seas, causing the changes in the depositions from sandstone to

limestone or shale, and the reverse. These oscillations are the subject of brief remark in the next section, on the geography of the period.

IV. General Observations.

1. **North American Geography.**—On p. 136 a map is given purporting to represent the general outline of North America at the close of the Azoic period. It is there stated that there may have been other lands above the water, especially about the summits of the Rocky Mountains and the regions beyond, making islands, large and small, in the great continental sea; but that the continent, in a general way already defined as to its ultimate outline, lay at no great depth beneath the surface of the water. The facts gathered from the rocks of the Primordial period throw additional light on early American geography.

(1.) *Northern border of the interior basin.*—We learn from the beds of the first or Potsdam epoch that along the northern border of the United States the waters were shallow, and that there were beyond doubt coasts and exposed sand and mud flats. The ripple-marks, so common in the strata both of New York, Canada, and the West, must have been formed either along a sandy beach or over a shallow bottom. The alternation of oblique and horizontal lamination in many layers (fig. 61 *e*, p. 93) is evidence of ebbing and flowing tides. The wave-lines show where the waves actually dashed over the sands of a coast. The various inclinations of the lamination (like fig. 61 *f*, p. 93, drawn from the Michigan Potsdam beds) point out the rocks as once wind-drifts of sand that had been decapitated again and again by storms; and the tracks of crustaceans, as Logan has observed, as well as the mud-cracks, could only have been made upon land above the level of the sea. The worm-burrows (Scolithi) in the sand-rocks were made in the sands near tide-level, or not far below. In fact, sandstone itself, as will be shown in a future chapter, is evidence to the same purport; for the sands as well as pebbles of marine formations are accumulated only along shores and within a narrow range of soundings. Hence the prevailing sandstones and conglomerates of the Potsdam formation indicate that there were no deep seas where these rocks were laid down. Thus, from New York through Canada, Michigan, Wisconsin, Minnesota, Iowa, and Nebraska, to the Black Hills, and the Laramie Range on the Rocky Mountains, we are enabled to run a line of soundings for the Potsdam period. When the layers of the Potsdam sandstone that now skirt the Black Hills of Dakota were forming, the hills stood above the sea, and the

materials of these layers were the moving sand and pebbles of the shore.

(2.) *Interior basin.*—South of this northern line, over the interior continental basin, whatever Potsdam rocks exist are mostly concealed from view; so that we fail of direct evidence as to the depth in that region. The rocks in Texas, however, bear the same testimony as those of the North. But we have indirect evidence with regard to the depth of the interior basin, in the facts observed along the Appalachian region, its eastern border. The sandstones and conglomerates of northern Vermont, Pennsylvania, Virginia, and Tennessee, afford proof of shallow waters and emerged flats like those of New York and the States west. There are more shales; but the interstratified sandstones still show that there was no deep ocean along the Appalachian region. Moreover, in Pennsylvania, Virginia, and Tennessee there are worm-burrows in the sandstones, as in New York. Thus, we make out a region of shallow waters and exposed sands along the Appalachian region, during a part at least of the Potsdam epoch. If, then, there were shallow waters on this eastern border and along the north, we may feel confident that there were no deep seas over the interior basin, although it is probable that the waters deepened from the northern coast-lines southward; and, as the Appalachians follow the general course of the existing coast, there is ground for full assurance that the general shape of the future continent was marked out in that early period.

(3.) *Eastern border.*—On the eastern border of the continent, in Newfoundland, and at Belle Isle, there is similar evidence of shallow waters or emerging sands. Besides the occurrence of a considerable thickness of sandstone, the rock at Belle Isle contains the borings of the Scolithus. There are also fossils; and above the sandstone occur beds of fossiliferous limestone, which may be additional proof that the seas were not very deep.

(4.) *Appalachian region.*—But the great thickness of the deposits along the Appalachian region gives further evidence that the future history of the Atlantic border was already foreshadowed in Primordial time.

Even the shales which abound in these Appalachian beds are no proof of deep seas, as such deposits form along coasts and not in the depths of an ocean. A few hundred feet, or a thousand at most, are all the depth that can be deemed probable for the formation of any shale. This is proved by the facts in existing seas. They may originate in deeper waters; but such cases are exceptions. Moreover, at Georgia, in Vermont, where the rocks are shales, the

large Trilobites indicate that the beds are rather the accumulations of sheltered bays than of deeper off-shore waters. The fossils of Swanton, Vermont, suggest the same conclusion. The intercalated sandstones and conglomerates, and even the limestones of the Quebec group, Taconic rocks, and the Primordial series in other parts of the Appalachians, require, for each, moderate depths at intervals, in the progress of the great formation.

But, taking the facts as allowing of even a thousand feet of depth for the deposition of a large part of the shales (instead of the one to four or five hundred feet which we deem more probable), there are still several multiples of this thickness to account for along this Appalachian region. The facts, therefore, show that this border portion of the continent must have been subject to great oscillations, resulting in a subsidence nearly equal to the thickness of the deposit. The oscillations were such as would produce the alternations of rock in the series, bringing the land near or to the surface for the accumulations of sandstones and conglomerates, and depressing it again somewhat for the shales. These were early movements in that system of change which resulted in the evolution of the Appalachian chain.

The transition from the region of these oscillations to the interior basin is singularly abrupt, as shown by the wonderful contrast in the thickness of the strata. This contrast has been made still stronger in later time by the foldings and disturbances along the Appalachians. The boundary between the two is the course of a series of great faults in the strata,—as has been pointed out by different geologists,—which follows the general direction of the Appalachian chain. Directly on its course are the waters of the Hudson and Lake Champlain. From the north extremity of Lake Champlain, as Logan has mentioned, the line stretches north to Quebec, on the St. Lawrence, thence follows the river, and, finally, bends around to Gaspé on the Gulf of St. Lawrence. In consequence of the faulting, the rocks of the Potsdam period on the east side were raised several thousand feet above the level of those on the west. The existence of this line of faults was predetermined in the oscillations; but when it was made is not ascertained. It was natural that the oscillation of the unstable border of the continent against the more stable interior should sooner or later have ended in such a catastrophe.

(5.) *Change of condition between the Potsdam and Calciferous epochs.*—In passing from the Potsdam to the Calciferous epoch, there was a change in the condition of the continental seas, so that the rocks afterwards made were to a considerable extent limestone: it is

probable that this change consisted in a deepening of the waters through subsidence. In the Potsdam epoch the continent, when the rocks were forming, lay for the most part near the water's level, washed by the ocean's tides,—a condition favorable for the accumulation of sand deposits. In such a case the waters would be too impure from disturbed sediment for the formation of limestone. Such an amount of subsidence was therefore required as would give clear and pure waters,—perhaps not more than a hundred feet; for the limestone of the coral islands is all made within that depth. Moreover, the alternations of sandy strata with limestone, so marked in Missouri, imply several oscillations of level over the interior basin during the Calciferous epoch. These oscillations are also indicated by the succession of strata in the Quebec group and in other parts of the Appalachian region. To the east, at the Mingan Islands, there were sandstone deposits in the earlier part of the Calciferous epoch, but others of limestone before its close.

(6.) *Lake Superior Sandstone beds and Trap rocks.*—The deposits of the Potsdam period in the vicinity of Lake Superior differ from others of the interior basin in their great thickness (p. 195); but they are also peculiar in their connection with the eruption of igneous rocks. The evidences of igneous eruption are very numerous on both the north and south shores of the lake; and Isle Royal, standing in the lake, abounds in trap rocks of this period. Such a region of fires might naturally be one of extensive subsidence,—no uncommon phenomenon in volcanic countries. This would give an opportunity for the formation of thick deposits; while if the waters had been permanently shallow the marine formations must have been thin, as they are in the peninsula of Michigan; for they could not have much exceeded the depth of the waters. This region of Lake Superior and the other great lakes lies directly against the Azoic; that is, it is between the region of progress on the south, which was undergoing frequent changes of level through the Silurian ages, and the more stable Azoic of the north. Here the series of depressions were formed which are now the lakes; and these igneous eruptions through the fractured crust of the earth seem to have been an incident in the subsidence that was producing the basin for the largest of all the lakes, Lake Superior. Lake Champlain also lies along the borders of the Azoic, and has the Silurian of New England on its opposite side.

The thick sandstones, conglomerates, and shales of the Huronian series occur in this same lake-region, and seem to show that the first commencement of the lake-history dates as far back at least

as the Huronian period in the Azoic. The depression may not have begun at that time; but the subsidence attending the formation of the thick deposits was an early one in the series that ended in giving the main features to the present lake-region.

(7.) *Atlantic currents.*—From the map, p. 136, it is apparent that the northern oceanic current of the Atlantic would have traversed New England, New York, and the Appalachian region to the southwest, while the warmer Gulf Stream would have in part followed its present course and partly have flowed over the Gulf of Mexico and up the interior sea of the continent.

2. **Origin of the material of the rocks.**—(1.) *Sandstones, shales, and conglomerates.*—The Azoic age had left the earth with a surface of rock more or less covered with gravel and sand both above and below the water. The waves, running streams, and slow wear and decomposition through atmospheric causes, were working out their legitimate results during the closing part of the age, as well as earlier when the Azoic rocks themselves were accumulating. The surface could not have failed to be extensively spread with earth, and, at the opening of the new age, this earth or gravel would have made the sand-flats and higher fields that were exposed over the half-submerged continent, as well as the bottom of the seas.

From this material and the accessions derived through subsequent wear and decomposition, all the Potsdam beds and all later rocks of mechanical origin (exclusive of limestones) have to a great extent been made. This material has been worked over again and again, the accumulations of one age being in part distributed anew to make the rocks of a later; and by this means the geological series, with the exception stated, has been in the main built up. The rocks of igneous origin have added to the stock only an inconsiderable proportion of the whole amount, and those of chemical origin a much smaller fraction.

The beds of sandstones, shales, and conglomerate of the Potsdam period, we thus conclude, derived their material from the sand-flats, from the higher gravel-fields which the encroaching waves and running waters would level and carry off, and from the rocky Azoic hills and mountains that were subject to degradation by streams and decomposition. In an age without land-vegetation to bind the soil, the degrading-process would have been more complete than at the present time. These materials were spread out in layers by the waves and currents over the continental regions; and the animals, which had a living-place in the mud or sand, found there a burial-place also, to remain in many instances as fossils, in attestation of the life of the period.

(2.) *Limestones.*—The limestones of the Silurian and later ages have nearly all been made through the wear and accumulation of shells, crinoids, and corals, or the calcareous relics of whatever life occupied the seas. The great limestone formations of existing coral seas are modern examples of the process.

Among the beds of the Potsdam period, the magnesian limestone strata of the Quebec group contain numerous fossils, and thus show that they are marine, and that they have the origin above mentioned. The extensive magnesian limestones of the Mississippi valley have the same composition, and are similar in compactness; and the natural inference is that they were also of organic origin. But over extensive regions they do not contain a single fossil. Yet it is to be remembered that the sea which grinds pebbles and sand and makes fine sandstones may also grind shells and make an impalpable limestone. This is abundantly exemplified in coral-regions; for a large part of the limestone there made of corals and shells is as compact and unfossiliferous as the magnesian limestone in question.

The only other mode of origin is by chemical deposition. This could not have taken place in the open seas; for, owing to the oceanic currents, the waters have a remarkable uniformity of composition, and no local depositions can take place. It requires, therefore, an elevation above the sea, and the existence of calcareous mineral springs,—and springs on a wonderfully vast scale, for a formation as extensive as the one in question. Such a condition of things is improbable. Moreover, the depositions would have a structure wholly unlike that of the magnesian limestone. Whoever has seen the travertine beds of Tivoli—which are the largest of the chemical calcareous deposits formed in the present era—will appreciate the wide distinction between a mass made up of a series of incrustations curving with all sorts of fantastic irregularities, and the dense, even-grained limestone of the Calciferous epoch. The oolitic structure of part of this limestone has a parallel in the oolitic coral rock of Key West, which is also without imbedded corals or shells.

It is not impossible that the strata may have been made of microscopic organisms: the shells of Rhizopods, which have contributed so largely to chalk (though not commonly distinguishable in the mass), have been detected in the Lower Silurian of Russia, in "green-sand" like that of the Potsdam period (pages 174 and 176), and abundantly in the "green-sand" of the Cretaceous formation; so that the existence of this material leads the geologist to suspect at once that of the Rhizopods.

Another supposition is this: that the continent may have had its borders so raised that the interior was a salt-water sea, shut off from the ocean, and here the waters—more calcareous in that period than now—deposited the limestone; and that new accessions of calcareous material might have been received either through occasional incursions of the ocean, or through streams flowing from the land. A rock thus made, supposing the method possible, might be much like the Silurian limestone in compactness and texture.

3. **Climate.**—No marked difference between the life of the Primordial rocks in warm and cold latitudes has been observed; and there is wanting, therefore, all evidence of a diversity of climate and of oceanic temperature over the earth's surface. With a warm and equable climate, the atmosphere would have been moist and the skies much clouded, but storms would have been less frequent or violent than now. The eyes of the Trilobite, as Buckland observes, indicate that there was the full light of day, and therefore that sunshine alternated with the clouds as now.

4. **Life.**—(*a.*) *Grades of life.*—The system of life began (1) with marine species; (2) with species of three sub-kingdoms, those of Radiates, Mollusks, and Articulates; but (3) with the inferior species in each: the Sertularids being the lower Acalephs; Crinoids the lower Echinoderms; Brachiopods the lower Mollusks; and Lingula and Orthis among the lower Brachiopods; Gasteropods (Univalves) with an entire aperture to the shell, the lower of Gasteropodan Mollusks; Orthocerata, or the straight-shelled Cephalopods with plain septa, the lower of Cephalopodan Mollusks; marine worms, the inferior group of Articulates; Trilobites, Phyllopods, and Cyprids among the lower of Crustaceans; and Paradoxides and the associated genera of Trilobites among the lowest of the group of Trilobites. None of the genera of ornamented modern sea-shells have been observed, and none of those having a beaked aperture to the shell; no land or fresh-water shells; no shrimps, lobsters, or crabs (Macrourans or Brachyurans); no insects; no relics of fishes, reptiles, or mammals.

While, however, the species were inferior species in the tribes represented, they were not necessarily the very lowest. For Polyps are, as a class, the lowest of Radiates, and yet it is not certain that any Polyp-corals were in the Primordial fauna,—none being reported from the European Primordial period, and those so called found in the American rocks being probably Sponges. Trilobites, although belonging to the inferior of the grand divisions of Crustaceans, the Entomostracans, stand at the head of that division, if not intermediate between them and the Tetradecapods, the next

higher group. The Phyllopods are other Entomostracans, and in some respects they constitute a group of high grade, having affinities with the Macrourans as shown in the general form of the species. The Trilobites and Phyllopods are examples of *comprehensive* types (*synthetic* of Agassiz),—types comprehending, along with their own characteristics, some of those of other tribes which were yet uncreated, but which were to exist in the future unfolding of the system of life.

As far as has been deciphered in the history of the Primordial period, there was no green herbage over the exposed hills; and no sounds were in the air save those of lifeless nature,—the moving waters, the tempest, and the earthquake.

(*b.*) *Exterminations.*—The life of the Potsdam period changed much during its course, and at one time—the close of the first epoch—there was nearly a complete extermination of the species, requiring a repeopling of the seas for the succeeding epoch. Two or three species, including a Lingula, exist, but the others do not reappear. Among the Trilobites, the genus Paradoxides, some of whose species were the largest of known Crustaceans, became entirely extinct; most of the other genera remained, but were represented by new species.

At the end of the Calciferous epoch there was a second extermination, obliterating wholly the life of the Primordial period. Some species had disappeared before in the progress of the epoch, for these destructions were not confined to the grander transitions in the strata; and there had also been new additions to the species at intervals, judging from the successions in the Quebec rocks. These exterminations and creations in the progress of a period, and more general exterminations and creations at the end of an epoch or period, were a common feature throughout the earth's geological progress.

5. **Reality of the Primordial or Potsdam period in America, and its equivalency with the European.**—The fact that the Potsdam and Calciferous epochs constitute together one period in the history is shown by the transitions of the strata, and more especially by the resemblances between the two in living species. This has become more apparent since the recent discoveries in the Canadian geological survey under Sir William Logan. The types of life of a period are of two classes: those of one class are characteristic of the period, and have their fullest exhibition in its course; the others look onward to a fuller expression in some part of future time. The genera of Gasteropods and Cephalopods are of the latter kind; for *Pleurotomaria*, *Maclurea*, *Orthoceras*, and other genera of these tribes

have only their beginning here; they have a much larger representation in species during later periods. But the genera of Trilobites are in a large degree peculiar to the Primordial. *Paradoxides, Peltura, Dicellocephalus, Menocephalus, Arionellus, Conocephalus,* have their whole existence in the Potsdam period. The first two are eminently Primordial in character. The others approximate more to genera of the next period.

The correctness of uniting the Potsdam and Calciferous epochs in one period is apparent in the number of these Primordial genera of Trilobites which the two epochs have in common. Paradoxides and Peltura are alone in being confined to the first epoch. The others mentioned have species in both, and there are quite a number of Calciferous species of Dicellocephalus, Bathyurus, and Conocephalus.

The equivalency or synchronism of the European and American Primordial period is looked for, not in the sameness of species,—for none are known to be common to the two continents, although one or two are so suspected,—but in an identity in a prominent part of the genera. In accordance with this, we find the life of the world on both sides of the Atlantic commencing with species of Lingula, Obolus, Orthis, Theca, Scolithus, and the Trilobites, Paradoxides, Peltura, Conocephalus, Arionellus, Agnostus, and others.

But, while a general equivalency is apparent, there are marked peculiarities, which are brought out especially in the later part of the American Primordial. There are Gasteropods (Pleurotomariæ) and Cephalopods (Orthocerata) even in the earlier epoch of the American Primordial, while no species of either group have been reported from any part of the European; and in the later American epoch, Gasteropods and Cephalopods are represented by many species of several genera. From this great discrepancy it is natural to conclude that the American Primordial period was continued on in time beyond the European.

The Calciferous formation has an exact representative in Great Britain in the Sutherland limestone of the Northwestern Highlands, among whose fossils are species of *Ophileta* and others characteristic of the beds. The Calciferous beds of America are separated by some geologists abroad from the Primordial or Potsdam period; but, as appears above, this is not sustained by investigation.

Should it be proposed to divide the beds differently, and transfer the *Dicellocephalus* strata of the Upper Mississippi to the Calciferous, in order to remove these Trilobites from the Potsdam,—or to transfer the *lower* limestone of the Quebec group to the Potsdam, so as to place all the *Dicellocephali* in the latter (which would thus be done),—objections would be equally encountered. (1.) No break in the strata sustains such a course; (2.) The Calciferous and Potsdam

epochs are still united by having several species in common, while no Calciferous species pass into the Chazy; (3.) The genus *Conocephalus*, Primordial in Europe, is well represented in the Calciferous; (4.) Gasteropods and Cephalopods, not Primordial in Europe, are not by these means removed from the Potsdam.

2. TRENTON PERIOD (3).

Epochs.—1. CHAZY (3 *a*), or epoch of the Chazy limestone. 2. TRENTON (3 *b*), or epoch of the Birdseye, Black River, and Trenton limestones.

I. Rocks: kinds and distribution.

1. AMERICAN.

The Trenton period was characterized by a profusion of Brachiopods, Trilobites, and Orthocerata, and by the making of limestone strata, almost of continental extent, out of the shells and other calcareous relics of the living species. The rocks extend over a large part of the continent east of the Mississippi, and beyond towards the Rocky Mountains.

The Chazy limestone (3 *a*), or that of the Chazy epoch, is so named from the town of Chazy, in Clinton co., N.Y., on the west side of Lake Champlain, where the formation occurs. The rock is mostly a grayish limestone, and the fossils are remarkable for being, with few exceptions, quite small.

The Trenton limestone (3 *b*) derives its name from the well-known locality of the rock along the gorge at Trenton Falls in central New York. The rock is gray to black in color, the dark colors predominating in New York, and the grayish in the West.

The thickness of the whole series in northern New York and Canada, towards the Azoic, where probably lay the ocean's border, is generally from 100 to 300 feet; yet in the region of Ottawa—a great St. Lawrence Bay in the earlier Silurian era (see map p. 170,)—it is about 800 feet. West of the Appalachians the thickness averages about 300 feet. Along the Appalachian region, in Pennsylvania, it is from 300 to 500 feet.

1. **Chazy epoch.**—(*a.*) *Interior Continental basin.*—The Chazy limestone outcrops at different places in northern New York, in the vicinity of the Azoic (though not along its more southern border); also in Canada, around the Trenton limestone of the Ottawa basin, and from the head of Lake Ontario westward to Lake Huron. The thickness in some parts of New York is 100 to 150 feet. Occasionally it graduates into the next rock below, the Calciferous sandrock, so that the two are separated with difficulty. In the region of the Upper Mississippi, in Wisconsin, Minnesota, and Iowa, there is a sandstone called by Owen St. Peter's sandstone, from a locality at the mouth of St. Peter's River. It

overlies the Calciferous, and underlies the Trenton: its relation to the Chazy, beyond this of position, has not yet been determined.

The Chazy limestone has been stated to occur in Northern America, in the Winnipeg region, west of the Azoic.

(*b.*) *Appalachian region.*—The Chazy has not been recognized along any portion of the Green Mountains. It is supposed to be represented in the upper part of the Quebec group. In Pennsylvania, there is a magnesian limestone, 5000 to 6000 feet thick in some places, corresponding to the Trenton period, according to H. D. Rogers; but what part is Chazy is not yet ascertained.

(*c.*) *Eastern border.*—A limestone of the Chazy epoch occurs at the Mingan Islands, in the Gulf of St. Lawrence.

(*d.*) *Arctic region.*—Limestone strata, containing Chazy fossils, have been observed in the Arctic, on King William's Island, North Devon, and at Depot Bay in Bellot's Strait (lat. 72°, long. 94°). The species *Orthoceras moniliforme* Hall, and a Maclurea (*M. Arctica* Haughton) near *M. magna*, have been observed. The limestone is in part a cream-colored dolomite.

2. Trenton epoch.—(*a*). *Interior Continental basin.*—In New York and Canada, the Trenton limestone directly overlies the Chazy. The lower part in New York is made up of the Birdseye and Black River limestones (the latter the upper); and these same subdivisions have been distinguished in much of the Mississippi basin.

The Birdseye limestone is so called from whitish crystalline points or spots distributed through it. This peculiarity, however, is not always present, and occurs in other limestones. The color is drab or dove-colored and brownish, and not so dark as that of the overlying beds.

The Black River limestone is named from Black River, east of Lake Ontario, in New York, along which there are the best exposures of it. The color is generally dark, nearly black.

The Trenton limestone in New York is grayish-black to black. It is sometimes bituminous, especially in its upper portions. Its layers are often thin, and frequently argillaceous, and beds of shale in many places intervene. The black color is due to carbon or bitumen, as is shown by its burning white.

The Trenton limestone has been recognized in the Winnipeg region in British America, as well as over much of the Mississippi basin. The Galena or lead-bearing limestone of Wisconsin and the adjoining States in the West constitutes the upper portion of the Trenton series, and often alternates with layers of the Trenton limestone.

The rock, though generally common limestone, sometimes includes layers of magnesian limestone; and the Galena beds are generally magnesian. (See analysis on p. 84.)

The thickness in New York seldom exceeds 300 feet. At Montreal it is 600 feet (Logan); on the Manitoulin Islands, in the St. Lawrence, not over 300 feet; in the Michigan peninsula, about 32 feet (Winchell); in the region more to the west, usually about 300 feet: in middle Tennessee, where the beds are called the Stones River group by Safford, 200 to 300 feet; in Missouri, 400 to 500 feet (Swallow). In Iowa the Galena limestone is 250 feet near Dubuque, and the Trenton 20 to 100 feet (Hall).

(*b.*) *Appalachian region.*—The limestones of the Trenton epoch have great

thickness in Pennsylvania,—probably 2000 feet or more. In *eastern* Tennessee the thickness is more than double that in the central basin of the State, being at least 500 or 600 feet (Safford).

(*c*.) *Arctic region*.—The Trenton limestone has been identified in the Arctic on the west shore of King William's Island, at Fury Point on North Somerset, on the east and west sides of Boothia. The Boothia rock is a dolomite, containing carbonate of lime 54.92, carbonate of magnesia 42.57, clay and oxyd of iron 2.51.

3. **Minerals.**—The lead-mines of Wisconsin and the adjoining region are situated in the Galena limestone,—a rock named from the mineralogical designation of the common ore of lead, galena. The ore occurs in large irregular beds or extended masses, sometimes spreading like veins, though not properly of this nature. The lead-region of Wisconsin and Illinois, according to Owen, is 87 miles from east to west and 54 from north to south; and throughout much of this region traces of lead may be found. The beds resemble in position the lead-mines of Missouri; but the latter occur in a limestone of the Calciferous epoch. These mines of the Upper Mississippi have been the subject of a recent report by J. D. Whitney.

2. European.

Rocks of the Trenton period occur in Great Britain and many parts of Europe; and by their general distribution they show that they have the same continental character as in North America.

In England, the rocks, instead of being limestones, are almost solely shales and shaly sandstone (flags), with only thin beds of limestone. They include the Llandeilo flags and shale, which are many thousand feet thick, succeeding to which, as the following part in the series, are the Caradoc sandstone of Shropshire and the Caradoc or Bala formation of Wales. The latter are supposed to represent the American Hudson period. Among the Bala beds are some thin layers of limestone. The thickness of the Lower Silurian of Great Britain above the base of the Llandeilo formation of Wales is estimated by Murchison at 18,000 feet.

In Spain, also, there are schists and sandstones, with some limestones. In Scandinavia there are limestones overlaid by slates and flags; and in Russia and the Baltic provinces, mainly limestones.

It thus appears that along the border regions of the European continent, as in England and Spain and Scandinavia in part, the rocks are mainly sandy or argillaceous, while over the interior, limestones abound.

I. Life.

1. American.

1. *Plants*.

Sea-weeds are the only fossil plants. Two of the species are represented in figs. 262, 263.

Specimens of Sea-weeds are rare. Fig. 262 is the *Buthotrephis gracilis*, and fig. 263, *B. succulosus*. The figures represent only portions of these plants. Many fossil Sea-weeds are not to be looked for in limestones.

Figs. 262, 263.

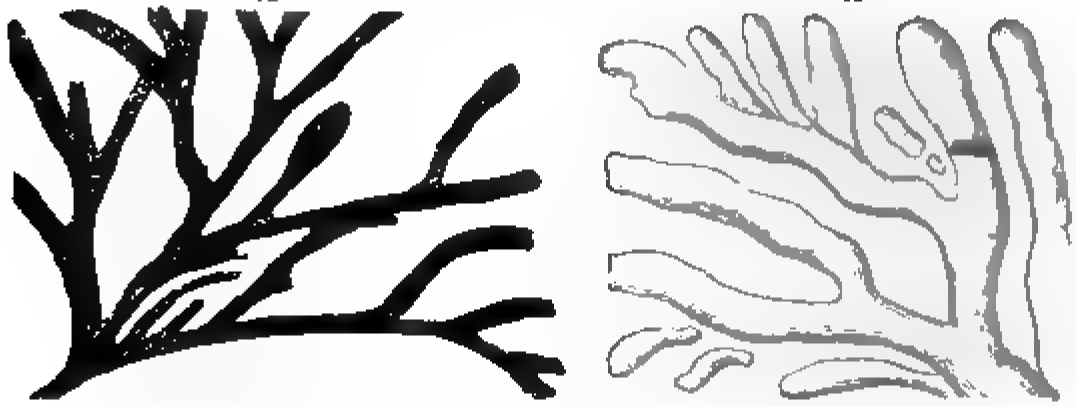


Fig. 262, Buthotrephis gracilis; 263, B. succulosus.

2. *Animals.*

The seas of the Trenton period were densely populated with animal life. Many of the beds are made of the shells, corals, and crinoids packed down in bulk; and the less fossiliferous compact kinds have probably the same origin, and differ only in that the shells and other relics were pulverized by the action of the sea, and reduced to a calcareous earth before consolidation.

With the Trenton period there appeared species of undoubted Polyps, the true coral animals of the seas (fig. 277, etc.); and the sub-kingdom of Radiates has hence all its three classes, Polyps, Acalephs, and Echinoderms, represented. These corals belong mostly to the *Cyathophyllum* family, and where they occurred they gave the aspect of a flower-garden to the sea-bottom in shallow waters. The Molluscan sub-kingdom included numbers of Conchifers and Bryozoans, as well as Brachiopods, Pteropods, Gasteropods, and Cephalopods; and all these divisions were well represented Both the Molluscan and Radiate sub-kingdoms were, therefore, fully unfolded in all their grand types, though not advanced to the high rank they afterwards attained. In the sub-kingdom of Articulates there is no progress above Worms and Crustaceans; and no trace of a Fish or of any Vertebrate has been found in the rocks of the period.

The prevailing types are—(1) *Brachiopods* (figs. 268–270, 286–300), whose shells outnumber and outweigh all other remains together; (2) *Orthocerata* (figs. 313–315), of the class of Cephalopods, which are numerous, and some of them ten to fifteen feet long and a foot in diameter; (3) *Crinoids* (figs. 264, 284, 285), which rank next to

Brachiopods in the profusion of their relics; (4) *Trilobites* (figs. 320–326), which are greatly multiplied in genera and numbers of species, and attain in some cases a gigantic size; (5) *Bryozoans*, a group including a multitude of delicate corals having minute cells (figs. 266, 267).

There were but few Polyp-corals, compared with the number in later periods. Single masses of the coral *Columnaria alveolata* H. (fig. 278) occur in the Black River limestone, weighing between two and three thousand pounds. Delicate, plume-like fossils, called *Graptolites* (p. 190 and fig. 281), were a feature of the seas, though still more common in the next, or Hudson, period. Cystids (figs. 265, 285) were the most characteristic kind of Crinoids. They belong in geological history eminently to this early era, reaching in it their greatest expansion. The Brachiopods were small species in the first epoch (figs. 268–270), but large and of many kinds in the following (figs. 286–300). The Trenton species were mostly of the Orthis family (the genera *Orthis*, *Orthisina*, *Leptæna*, and *Strophomena*); and with these there were species of the *Lingula*, *Discina*, and *Rhynchonella* groups,—the same families that were represented in the earlier Calciferous epoch. The genera *Rhynchonella* (fig. 270), which begins in the Chazy, and *Crania* (fig. 330), of the Trenton, have representatives in modern seas.

The small bivalve Crustaceans *Leperditiæ*, (fig. 276) occur in immense numbers in some places, as on the Ottawa in Canada, where a bed of limestone two feet thick is wholly made up of them; and yet the length of the shell is only one-ninth of an inch.

The huge Orthocerata exceeded in magnitude any existing Cephalopods, and were the great animals of the Trenton world,—the first in size and rank.

Characteristic Species.—1. *Chazy Epoch.*

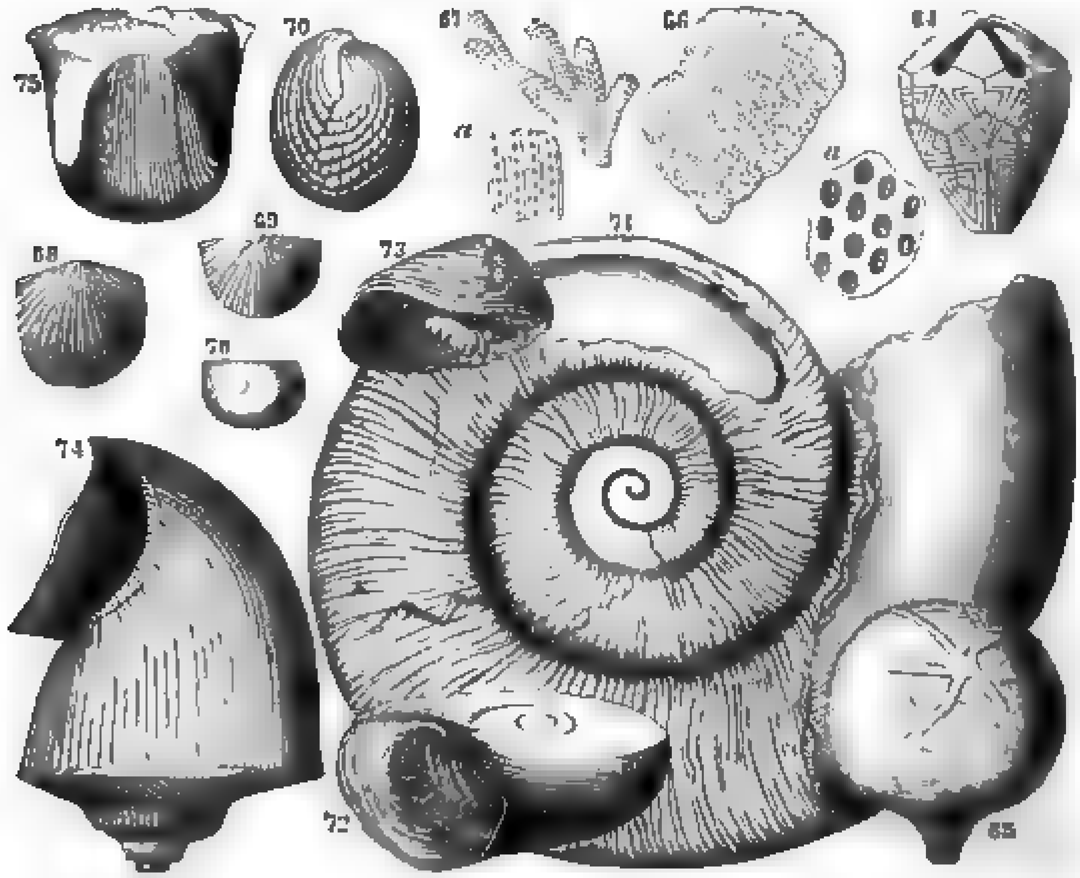
1. **Protozoans.**—*Sponges.*—*Eospongia Rœmeri* and *E. varians* B. occur at the Mingan Islands.

2. **Radiates.**—(*a.*) *Polyps.*—No species have been described. (*b.*) *Acalephs.*—Species of *Chætetes* and *Columnaria* (Billings). (*c.*) *Echinoderms.*—The Crinoids include as many known Cystids as Crinids. The following are a few of them:—

(1.) *Crinids.*—*Palæocrinus striatus* Billings (fig. 264), the body, showing the radiating ambulacral grooves (five) at top; *Blastoidocrinus carcharidens* B.,—the genus apparently of the Pentremite family, a family which makes its next appearance in the middle Devonian and abounds in the Subcarboniferous.—(2.) *Cystids*:—*Malocystis Murchisoni* B. (fig. 265), the body nearly spherical (whence the name, from the Latin *malum*, an apple), and having no arms, and the ambulacral grooves irregularly radiating. Another Chazy genus is the *Palæocystis* B., which includes Hall's *Actinocrinus tenuiradiatus.*

3. Mollusks.—(*a.*) *Bryozoans.*—Fig. 266 represents the *Retepora incepta*, a thin reticulate coral, the surface of which, magnified, is shown in fig. 266 *a*;

Figs. 264–276.



Radiates.—Fig. 264, Palæocrinus striatus, 265, Malocystis Murchisoni. Mollusks.—266, Retepora incepta; 267, Ptilodictya fenestrata; 268, Orthis costalis; 269, Leptæna plicifera; 270, Rhynchonella plena, 271, Maclurea magna, 272, M. Logani (× ⅓), 273, operculum of same; 274, Scalites angulatus; 275, Bellerophon rotundatum. Articulates.—276, Leperditia Canadensis, *var.* nana.

fig. 267, *Ptilodictya fenestrata*, a small branching species, covered with minute cells, and fig. 267 *a*, the surface magnified.

(*b.*) *Brachiopods.*—Fig. 268, *Orthis costalis* H.; fig. 269, *Leptæna plicifera* H.; *L. incrassata* H.; fig. 270, *Rhynchonella plena* H. (a side-view).

(*c.*) *Conchifers.*—None have been described.

(*d.*) *Gasteropods.*—Fig. 271, *Maclurea magna*, which is very abundant and sometimes has a diameter of eight inches; fig. 272, *Maclurea Logani*, showing the shell closed by its operculum; fig. 273, the operculum in side-view; fig. 274, *Scalites angulatus* Con.; fig. 275, *Bellerophon* (*Bucania*) *rotundatum*.

(*e.*) *Cephalopods.*—*Orthoceras recti-annulatum* H.; *O. tenuiseptum* H., a large species, with the septa thin and rather crowded.

4. Articulates.—(*a.*) *Trilobites.*—Among the species there are *Illænus Arcturus* H.; *I. crassicauda?*; *Asaphus obtusus* H.; *Asaphus* (*Isotelus*) *gigas* (fig. 320). There are also species of *Bathyurus* and *Ampyx* in the Canada rocks.

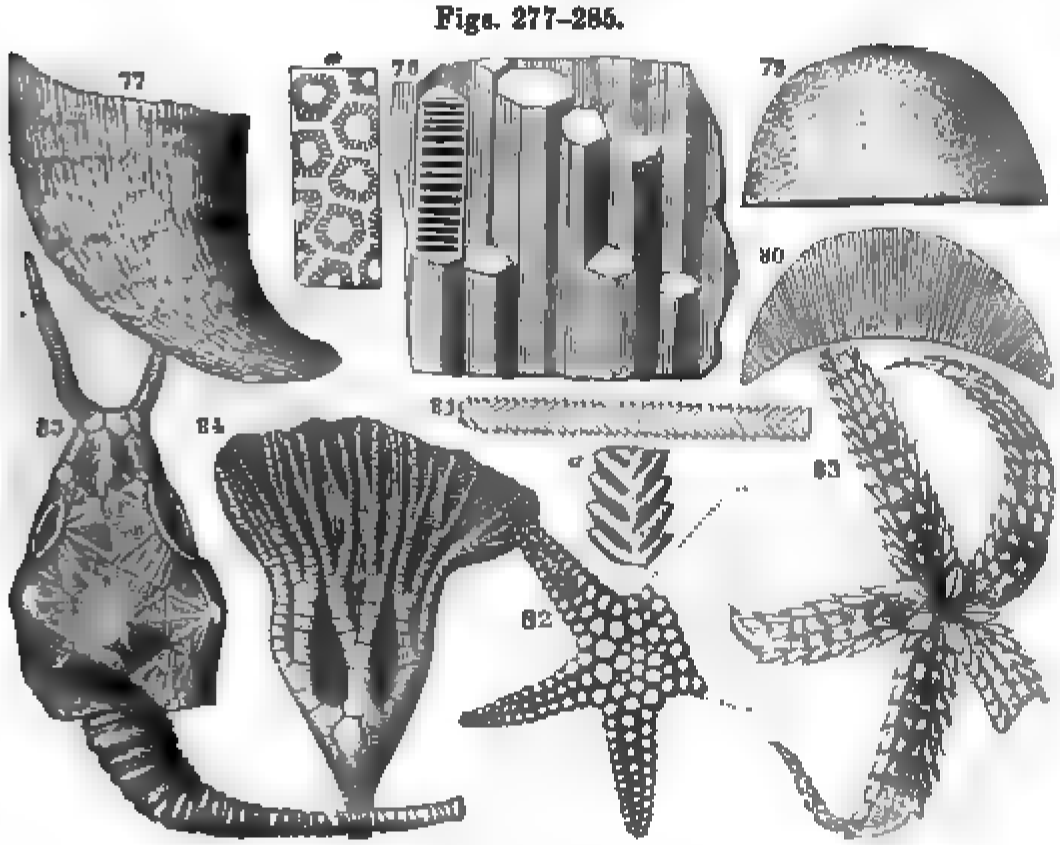
(*b*.) *Ostracoids*, or Bivalve Crustaceans.—Fig. 276, *Leperditia Canadensis* (var. *nana*) Jones.

2. *Trenton Epoch.*

1. Protozoans.—*Sponges.*—*Astylospongia parvula* B. occurs near Ottawa City, Canada. Several other species of sponge have been described by Rœmer from the rocks of western Tennessee.

2. Radiates.—(*a*.) *Polyps.*—True Polyp-corals (pages 162, 163) occur here. Fig. 277 is the *Petraia Corniculum*, a coral of the Cyathophyllum family, from

Figs. 277–285.



RADIATES.—Fig. 277, Petraia Corniculum. 278, *a*. Columnaria alveolata; 279, 280, Chætetes Lycoperdon; 281, *a*, Graptolithus amplexicaulis; 282, Palæaster matutina; 283, Tæniaster spinosa; 284, Lecanocrinus elegans; 285, Pleurocystis squamosus.

the Trenton limestone. When alive it had probably a circle of tentacles and a flower-like summit, resembling closely fig. 147, and it may have been richly colored. Fig. 278, a fragment of the *Columnaria alveolata* H., characteristic of the Black River limestone in New York, but occurring elsewhere in the Trenton limestone,—a section of one of the columnar cells shows the tables or partitions of the interior; fig. 278 *a*, top-view, showing the radiate cells; fig. 279, *Chætetes Lycoperdon* of the Trenton, a solid coral of a conoidal form, having a fibrous or fine columnar structure, as shown in the sectional view, fig. 280. A branching fossil, characteristic of the Birdseye, and called *Phytopsis tubulosus* H., is a coral of the genus *Tetradium*, having cells like fig. 338 *a*. The chain-coral (genus *Halysites*, a species of which is shown in fig. 336) has occa-

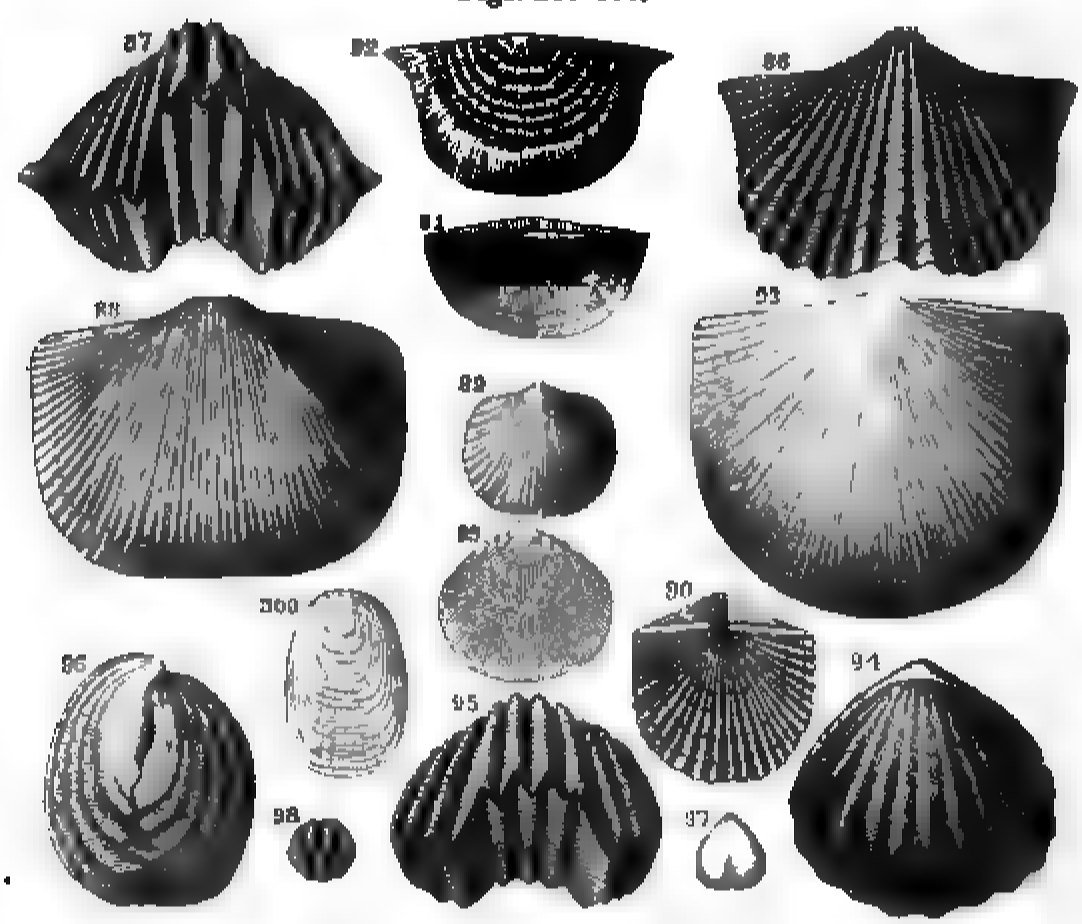
sionally been seen in the limestones of the Trenton epoch, as in the Galena limestone, and in Canada.

(*b.*) *Acalephs.*—Fig. 281 is the *Graptolithus amplexicaulis* H. of the Trenton, and 281 *a* an enlarged view. Agassiz refers also to the Acalephs the genera *Chaetetes* (fig. 279), *Favosites*, *Columnaria* (fig. 278), and the related corals having the cells divided by horizontal partitions, as explained on p. 162.

(*c.*) *Echinoderms.*—Fig. 282, the Star-fish *Palæaster matutina* H. of the Trenton; 283, *Tæniaster spinosa* B.; fig. 284, the Crinid *Lecanocrinus elegans* Billings; fig. 285, the two-armed Cystid *Pleurocystis squamosus* B., of the Trenton, in Ottawa, Canada.

The number of Cystids described by E. Billings from the Lower Silurian of Canada is 21; making in all for this era in North America, thus far known, 22; the Crinids of the same era amount to 50 species, and the Star-fishes to 11; 13 of the Crinids and 6 of the Star-fishes are Trenton species.

Figs. 286–300.



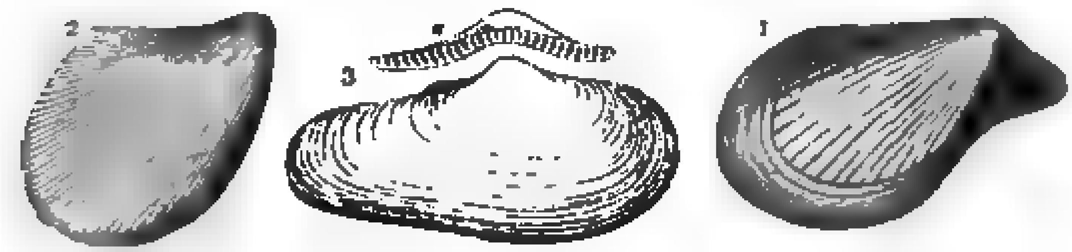
Brachiopods.—Figs. 286, 287, Orthis Lynx; 288, O. occidentalis; 289, O. testudinaria; 290, O. tricenaria; 291, Leptæna sericea; 292, Strophomena (Leptæna) rugosa; 293, Stroph. alternata; 294, 295, 296, Rhynchonella increbescens, 297, 298, Rhynchonella bisulcata; 299, Obolus filosus, 300, Lingula quadrata.

3. **Mollusks.**—(*a.*) *Bryozoans.*—Species of *Retepora* and *Ptilodictya* (related to figs. 266, 267) are common.

(*b.*) *Brachiopoda.*—Figs. 286, 287, *Orthis Lynx*; 288, *O. occidentalis*; 289, *O. testudinaria* Dal.; 290, *O. tricenaria* Con.; 291, *Leptæna sericea* Sow.; 292, *Strophomena rugosa* (formerly *Leptæna depressa*); 293, *Stroph. alternata*; 294–296, *Rhynchonella increbescens* H.; 297, 298, *Rhynchonella? bisulcata*.

(*c.*) *Conchifera.*—Fig. 301, *Avicula? Trentonensis* Con.; 302, *Ambonychia bellistriata* H., 303, *Ctenodonta nasuta*; also *Conocardium immaturum* B., of Black River limestone on the Ottawa, Canada, and species of *Modiolopsis*.

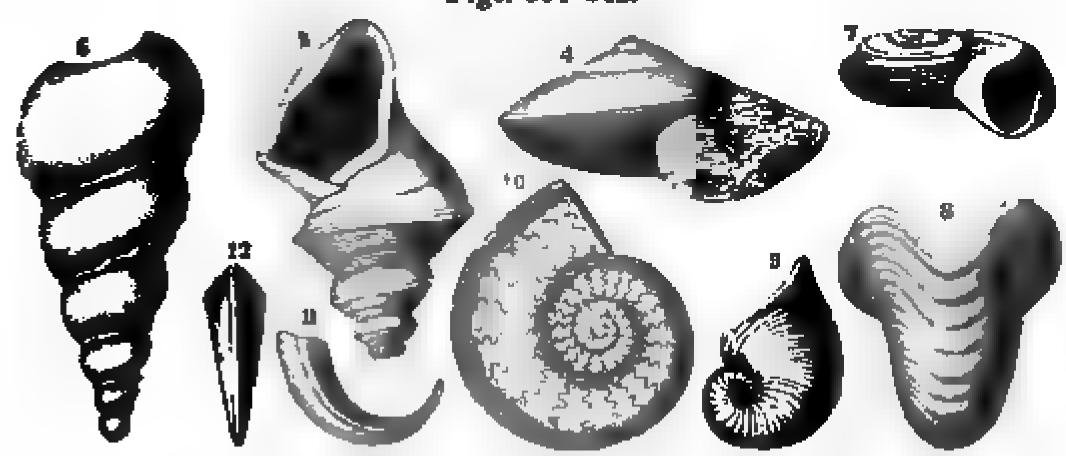
Figs. 301–303.



CONCHIFERS.—Fig. 301, Avicula? Trentonensis; 302, Ambonychia bellistriata; 303, Ctenodonta nasuta.

(*d.*) *Gasteropoda.*—Fig. 304, *Pleurotomaria lenticularis* Con., very common in the Trenton limestone; 305, *Murchisonia bicincta*; 306, *M. bellicincta*, often four inches long; 307, *Helicotoma planulata* Salter, from Canada; 308, *Bellerophon*

Figs. 304–312.



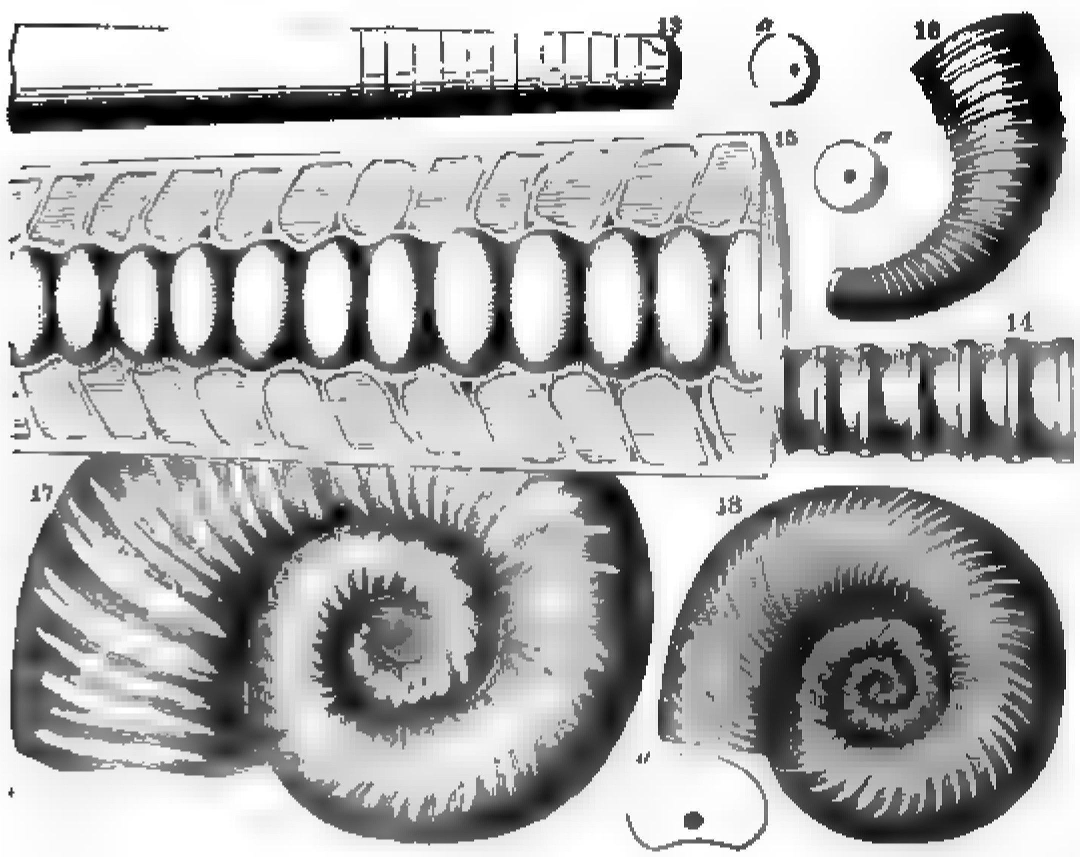
GASTEROPODS.—Fig. 304, Pleurotomaria lenticularis; 305, Murchisonia bicincta, 306, M. bellicincta; 307, Helicotoma planulata; 308, 309, Bellerophon bilobatus; 310, Cyrtolites compressus; 311, C. Trentonensis.

bilobatus, very common; 309, same, side-view; 310, *Cyrtolites compressus* H.; 311, 312, *Cyrtolites Trentonensis*, side-view. The genus *Cyrtolites* is like a partly-uncoiled Bellerophon, and is not chambered. There are also several Patella-like species of *Metoptoma* (formerly Capulus and Patella), a genus which began in the Calciferous beds.

(*e.*) *Cephalopoda.*—Fig. 313, *Orthoceras junceum* H., a small Trenton species; 314, *O. vertebrale* H., also Trenton, the figure reduced to one-third; 315, part of an *Ormoceras tenuifilum*, showing the beaded siphuncle and septa. The species is very common in the Black River limestone, and is sometimes over two

feet long: the genus *Ormoceras* is peculiar in the beaded form of the siphuncle. Other common species of the Orthoceras family are the *Endoceras proteiforme* H., and the *Gonioceras anceps* H. The *Endoceras* is the most gigantic known,

Figs 313–318.



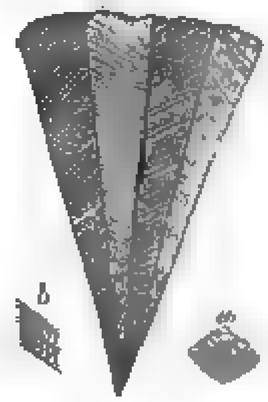
CEPHALOPODS.—Fig. 313, *a*, Orthoceras junceum; 314, O. vertebrale; 315, Ormoceras tenuifilum; 316, *a*, Cyrtoceras annulatum; 317, Cryptoceras undatum; 318, Trocholites Ammonius.

having attained a length in some cases of fifteen feet, and a diameter of nearly one foot. In the genus *Endoceras* (from the Greek κέρας, *horn*, and ἔνδον, *within*) there is a concentric structure of cone within cone. In the *Gonioceras* the septa or partitions are very much crowded and have a double curvature, and the siphuncle is central.

(*f*.) There are also curved species. Fig. 316 is *Cyrtoceras annulatum* H.; *a*, a transverse section, showing the position of the siphuncle; fig. 317, *Cryptoceras undatum* (*Lituites undata* H.), an abundant species in the Black River limestone; fig. 318, *Trocholites Ammonius* of the Trenton; 318 *a*, a transverse section. In *Cryptoceras* the spire is open at the outer extremity and the siphuncle is dorsal; while in *Trocholites* it is closed and very tightly coiled throughout. *Lituites*, another genus of the period, which first appeared in the Calciferous, differs from Cryptoceras in having the siphuncle subcentral. The genus *Phragmoceras* is peculiar in having the mouth of the shell very much contracted by a bending inward of the sides. A species, *P. immaturum* B., occurs in the Black River limestone of Canada.

Fig. 319 represents *Conularia gracilis* H., a delicate four-sided pyramid, apparently admitting of some motion at the angles, but having septa within in the smaller extremity (*a*), and supposed therefore to be the shell of a Cephalopod; *b* is an enlarged view of the surface.

Fig. 319.



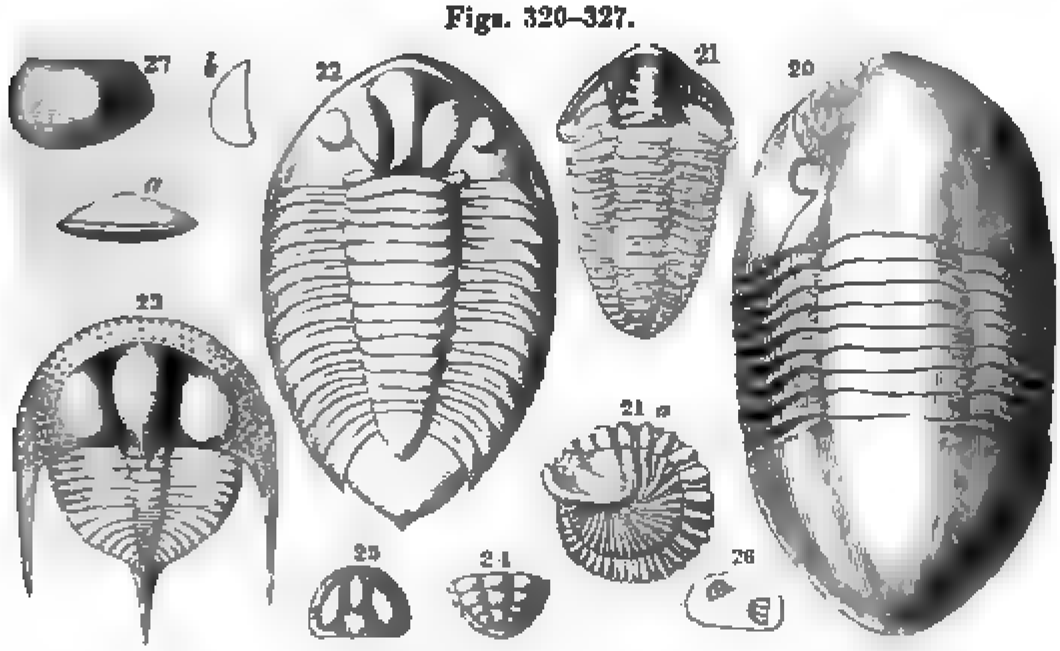
Conularia gracilis.

4. **Articulates.**—(*a.*) *Trilobites.*—Fig. 320, *Asaphus* (*Isotelus*) *gigas*, a small specimen; the species is sometimes ten inches or a foot long; fig. 321, *Calymene senaria* Con.; fig. 321 *a*, same rolled up, by bringing the tail to the head; fig. 322, *Lichas Trentonensis*; fig. 323, *Trinucleus concentricus*; figs. 324, 325, *Agnostus lobatus*, H., head and tail portions magnified; 326, natural size.

(*b.*) *Ostracoids.*—Fig. 327, *Leperditia Fabulites?* Con., natural size; *a*, *b*, transverse and vertical sections, the specimen from Canada (*L. Josephiana* Jones, who refers the species with a query to the *Fabulites* of Conrad).

In the State of New York the Black River limestone is especially remarkable for its great abundance of species of the Orthoceras family, among which are

Figs. 320–327.



CRUSTACEANS.—Fig. 320, Asaphus gigas (× ½); 321, *a*, Calymene senaria; 322, Lichas Trentonensis; 323, Trinucleus concentricus, 324, 325, Agnostus lobatus (× 4); 326, same, natural size; 327, *a*, *b*, Leperditia Fabulites (natural size).

the species *Ormoceras tenuifilum* H., *Endoceras longissimum* H., and *Gonioceras anceps*, which do not recur in the overlying Trenton limestone. Some of them are, however, found in rocks in Canada whose fossils are two-thirds those of the Trenton; and both there and in Tennessee, as well as other parts of the West, there is a mingling of Black River, Birdseye, and Trenton fossils, which proves that the rocks make but one group. (Billings.)

The number of Chazy species occurring in the Trenton group has not been recently announced.

2. European.

The same subdivisions of the kingdoms of life are represented in Europe as in America, the Radiate and Molluscan having their grander types brought out in species, while the Articulates appear only as Worms and Crustaceans, with Trilobites the predominant tribe. Moreover, the genera of Trilobites, Orthocerata, Brachiopods, etc., are, in the main, the same; and many species have been published as identical with American fossils. Among those species of wide range there are the following:—The species *Asaphus gigas*, *Trinucleus concentricus*, *Orthis striatula*, *Orthis Lynx*, *Strophomena alternata*, *Leptæna sericea*, *Murchisonia bicincta*, *Bellerophon bilobatus*, and others, occurring in the Llandeilo flags or their equivalents in Great Britain. *Trinucleus concentricus* is also reported from Bohemia; *Orthis Lynx* (or *biforata*), *O. striatula*, *Bellerophon bilobatus*, from Russia and Scandinavia. The group of Cystids reached a climax, as in America; the Bala limestone in Great Britain and equivalent beds in Bohemia and Sweden containing the species in greatest abundance, the number from these regions now known being over forty.

The annexed cut represents a few of the British species of the Llandeilo flags and Bala limestone.

Fig. 328, *Orthis Flabellulum*, one of the coarsely-plaited species of *Orthis*, and fig. 329, *O. elegantula*, both stated to range from the Llandeilo into the Upper

Figs. 328–334.

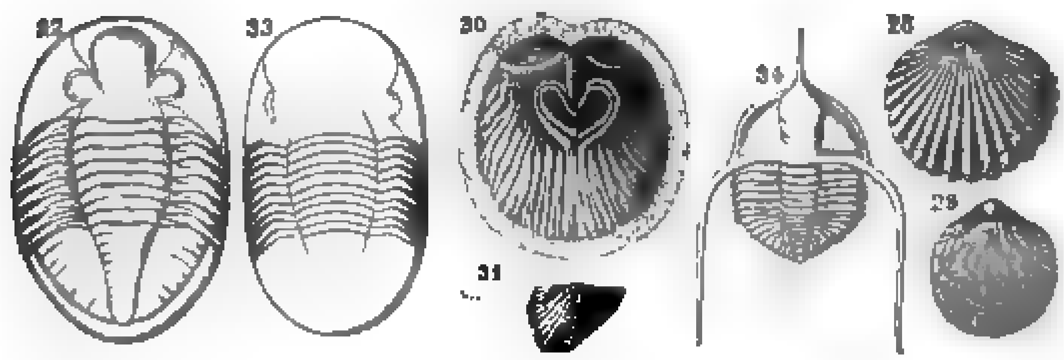


Fig. 328, Orthis Flabellulum; 329, O. elegantula; 330, Crania divaricata; 331, Conocardium dipterum; 332, Asaphus Powisii; 333, Illænus Davisii; 334, Ampyx nudus.

Silurian; fig. 330, *Crania divaricata*, the earliest species of the genus, adding another to the number of genera that range from the Lower Silurian to the present time; fig. 331, *Conocardium dipterum* of the Ayrshire beds; fig. 332, *Asaphus Powisii*; fig. 333, *Illænus Davisii* Salter; fig. 334, *Ampyx nudus*, a trilobite of the Llandeilo flags; fig. 177 (p. 151), *Calymene Blumenbachii*, which includes the *C. senaria* of the Trenton, reported to range from the Bala limestone into the Wenlock of the Upper Silurian.

The earliest *Rhizopods* (see p. 163) yet discovered have been found by Ehrenberg in the Obolus or Ungulite grit of Russia. The rock is in part a very soft green-sand; and the connection of the microscopic Rhizopod shells with the green grains shows, as Ehrenberg states, that it is of the same nature with the Green-sand of the Cretaceous. Among these fossils occur the three modern

genera *Textularia, Rotalia,* and *Guttulina.* Ehrenberg has also detected in this rock great numbers of Pteropods (related to *Theca*), and made out ten new species and four genera. The rock derives its name from its most common fossil, *Obolus Apollinis* (fig. 236), which is about as large as a small finger-nail. The *Siphonotreta unguiculata* (fig. 235) is another of its fossils. The age of the beds is either that of the Trenton or earlier.

3. HUDSON PERIOD (4).

Epochs.—1. UTICA, represented by the Utica shale (4 *a*); 2. HUDSON RIVER, or that of the Hudson River shale and some contemporaneous limestones (4 *b*).

In contrast with the Trenton period, the Hudson was pre-eminently a time of shale-making. Its surface-exposures in New York State are shown on the map, the region being that marked 4. Its life was abundant, and much resembled that of the Trenton period.

I. Rocks: kinds and distribution.

The *Utica shale* is the surface-rock along a narrow region in the Mohawk valley, N.Y. (see 4 *a* on map, p. 170), following a course nearly parallel with the outline of the Azoic farther north. The shale is in some places three hundred feet, or more, thick. It extends westward through Canada, and beyond, probably, into Wisconsin and Iowa, though a very thin deposit at the West. Along the Appalachians it occurs in Pennsylvania, and is from three hundred to seven hundred feet thick.

The rock is a crumbling shale, mostly of a dark blue-black or brownish-black color, and frequently bituminous or carbonaceous, —so much so as in certain places to serve as a black pigment. It sometimes contains thin coaly seams; and much money has been foolishly spent in searching for coal in this deposit. Thin layers of limestone are occasionally interpolated, especially in the lower part.

The *Hudson River shales* are exposed to view through the centre of New York, near the Mohawk, and westward from the northwestern side of Lake Ontario across Canada (following the course in New York) to Lake Huron (see map, fig. 205); also farther west, in Michigan, Wisconsin, and Iowa. The rocks are slates or crumbling shales, with some flagging-stone, in New York; but westward they become more or less calcareous.

The formation is represented in southern Ohio, about Cincinnati, by a thick limestone, called "Blue Limestone," but the beds are much interlaminated with a soft shale or marl; and this same rock

stretches across the Ohio into Kentucky and Tennessee, and westward into Illinois and Missouri. The greatest thickness in New York is nearly 1000 feet; in the Northwest it is very thin. Along the Appalachian region, in Pennsylvania, the rock is a shale, and has a thickness of 1600 feet or more.

In the Eastern border, at the island of Anticosti, the lower part of a limestone formation has been referred to this period; but recent investigations discredit it.

1. **Utica Epoch.**—(*a.*) *Interior Continental basin.*—The Utica shale is 15 to 35 feet thick at Glenn's Falls, in New York; 250 feet in Montgomery co.; 300 in Lewis co.

(*b.*) *Appalachian region.*—In Pennsylvania, the rock is a black shale, and in some parts it is fossiliferous. The thickness given by Professor Rogers in the Kittatinny, Nippenose, and Nittany valleys is 300 feet, and in the Kischicoquillas valley 400 feet.

2. **Hudson River Epoch.**—(*a.*) *Interior Continental basin.*—The Hudson River shales cover the region north of Lake Champlain, in Canada, west of the great fault which marks the western boundary of the Calciferous beds (see map, fig. 205), and they also lie over a small area near the centre of the Trenton limestone region of the Ottawa basin.

The thickness of the shales in Schoharie co., N.Y., is 700 feet (Vanuxem); on Lake Huron, 180 feet (Logan); in the Michigan peninsula, 18 feet (Winchell); in Iowa, 25 to 100 feet (Hall & Whitney). In Missouri, there are alternating strata of shale and limestone, 20 feet and less to 60 feet thick, the whole 120 feet in thickness (Swallow). In central Tennessee, the beds constitute part of the Nashville group of Safford (the lower part being Trenton), and consist of argillaceous limestone with many shaly layers: they are a few hundred feet thick.

(*b.*) *Appalachian region.*—In Pennsylvania, in the Kishicoquillas valley, the rock is a blue shale and slate, with some thin layers of calcareous sandstone, and the thickness is 1200 feet; in the Nittany valley, 700 feet; in the Nippenose valley, a little less. (Rogers.) In eastern Tennessee, the beds (corresponding to both the Utica and Hudson River epochs) are of great extent, and consist of calcareous and more or less sandy shales, abounding at times in Graptolites, with some thin layers of calcareous sandstone. They also occur of great thickness in Virginia, and reach down to Alabama.

(*c.*) *Eastern border.*—The limestone formation of the island of Anticosti, referred to the Hudson period, has a thickness of nearly 1000 feet. The limestone is often impure, and is interstratified to some extent with shales. The strata are nearly horizontal.

3. **Minerals.**—In the Utica shale, near Spraker's Basin, there is some lead-ore (galena) in small veins occupying the joints of the rock. Mr. Whitney has called attention to the large amount of carbon in the Hudson River shales from New York to Iowa, and its economical importance. In the rock near Savannah, Illinois,

he found the combustible portion amounting to 20.96, or about 21 pounds to every 100 of the shale; in that of Dubuque, 11 to 16 per cent.; in that of Herkimer co., N.Y. (Utica shale), 12 to 14 per cent.

The springs of Saratoga and Ballston rise from the lower part of the Hudson River shales.

II. Life.

The larger part of the species found in the American rocks of the Hudson period are identical with those of the Trenton, —although a considerable number are still peculiar to the period. The Utica shale, like most fine soft shales, contains few fossils,—the conditions of the formation having been such, apparently, as resulted in their complete trituration and destruction. The Hudson River beds, while partly as fine as the Utica shale, are often a little coarser in texture, as if formed of the kind of mud that abounds at moderate depths in marine life; and these somewhat sandy beds, as well as the limestones, are especially fossiliferous. The species in the limestones are often identical with those of the Trenton period,—a limestone period; while those of the shales are mostly different. The latter are, for the most part, those that live where the bottom is muddy; while the species whose relics make the limestones require clear waters, and flourish, like the shells of the coral seas, upon the submerged limestone reef which is in process of formation.

Plants.

The plants observed are all Sea-weeds, or Fucoids.

The great amount of carbonaceous material in the shales was probably derived mostly from these plants: it may have partly come from animal life.

Animals.

Where the rocks are sandy or shaly, there are few corals or Trilobites; and these Hudson River beds in New York are, hence, in strong contrast with those of the Trenton period. At the same time, Conchifers are much more numerous. This is the kind of difference that exists now between the species of a muddy bottom and those of a clear, coral-growing sea.

A striking feature of the shales is the abundance of Graptolites. They occur in the shales of Tennessee and the Upper Mississippi, as well as those of New York. These feathery species must have

grown thickly over the muddy sea-bottom; for the thinnest layers of the slates are sometimes crowdedly covered with their delicate tracery. In the limestone regions of the period, as about Cincinnati, corals and Trilobites are common, and one species of the latter, related to the *Isotelus* of Trenton Falls,—the *Asaphus* (*Isotelus*) *megistos*,—was twenty inches long and a foot broad.

Characteristic Species.

1. **Radiates.**—(*a.*) *Polyps.*—No corals have been described from the Utica shale. In the Hudson River beds in New York there are species of *Chætetes* related to those of the Trenton, and rarely specimens of the *Favistella stellata* H. (fig. 335), a columniform coral related to the Favosites, having stellate cells. This species is more abundant in the West. But few of the corals of the Hudson River epoch from Ohio and the States beyond have been described. Cyathophylla of the genus *Petraia* occur, as in the Trenton; also the earliest of the Chain-coral, or *Halysites* (*H. gracilis* H., fig. 336, from Green Bay, Wisconsin); also *Syringopora obsoleta* H. (fig. 337); and species of the genus Tetradium, as *Tetradium fibrosum*, fig. 338, *a*.

Figs. 335–339.

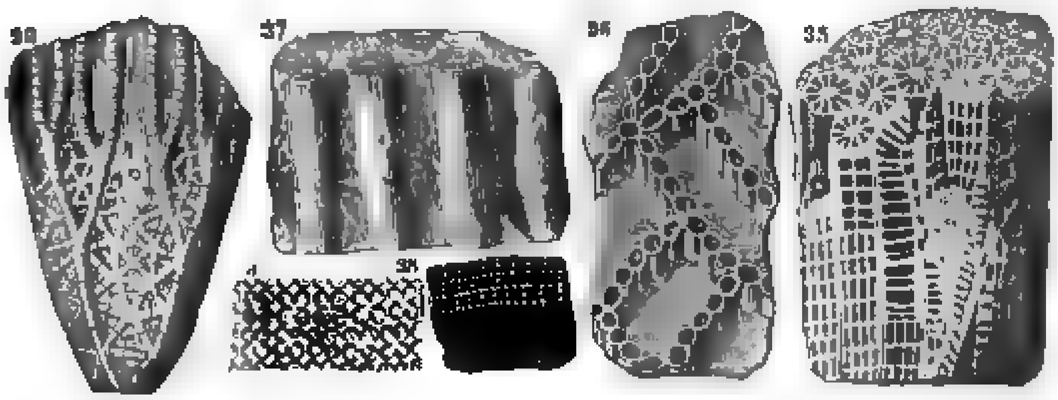


Fig. 335, Favistella stellata; 336, Halysites gracilis; 337, Syringopora obsoleta; 338, *a*, Tetradium fibrosum; 339, Glyptocrinus decadactylus.

(*b.*) *Acalephs.*—Fig. 251 (page 191) represents the *Graptolithus pristis* H., a species occurring abundantly in the Hudson River and Utica shales at many localities. Several other species have been described by Hall.

(*c.*) *Echinoderms.*—Crinids, Cystids, and Star-fishes occur in the rocks of the period. Among Crinids, the *Glyptocrinus decadactylus* H. (fig. 339) is not uncommon, occurring in New York, Ohio, Kentucky, and other States. Fig. 349 represents a large Star-fish from the Blue limestone of Cincinnati, as figured by J. G. Anthony, the original of which was four inches across.

2. **Mollusks.**—The Trenton Brachiopods *Leptæna sericea*, fig. 291; *Strophomena alternata*, fig. 293; *Orthis testudinaria*, fig. 289; *Orthis Lynx*, fig. 286; *Orthis occidentalis*, fig. 288; *Rhynchonella increbescens*, figs. 294–296; and some others, are continued in the Hudson River period; also the Gasteropods *Bello-*

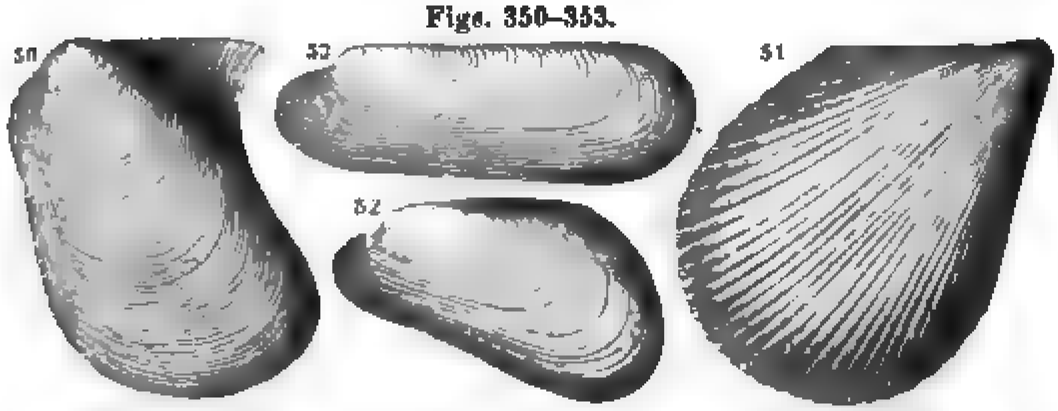
rophon bilobatus, figs. 308, 309; *Trocholites Ammonius*, fig. 318; and some Cephalopods of the Orthoceras family, etc. There are also in the rocks of this

Fig. 349.

ECHINODERM.—Asterias Anthonii.

period, and characteristic of them, the Conchifers *Avicula demissa*, fig. 350; *Ambonychia radiata*, fig. 351; *Modiolopsis modiolaris*, fig. 352; *Orthonota parallela* H., fig. 353. Among the Gasteropods occurs the *Cyrtolites ornatus*, near fig. 310.

Figs. 350–353.



CONCHIFERS.—Fig. 350, Avicula demissa; 351, Ambonychia radiata; 352, Modiolopsis modiolaris (× ⅔); 353, Orthonota parallela.

3. **Articulates.**—Among Trilobites, the *Asaphus* (*Isotelus*) *gigas*, and *Trinucleus concentricus*, continue on from the Trenton period; but the *A. gigas* is rivalled both as to abundance and size by the *A. megistos*, already referred to, found in Ohio and other States west. The *Triarthrus Beckii* is common in the Utica shale, and occasionally seen in the Trenton beds. The head-shield generally occurs without the body: fig. 354 represents its usual form, and fig. 355 the

Figs. 354, 355.

Triarthrus Beckii.

same entire. The body is much like that of a *Calymene* (fig. 321): it has a row of minute spines along the middle of the back.

III. General Observations on the Trenton and Hudson Periods.

Geography.—The Trenton and Hudson periods stand apart less through a difference of fauna than a geographical change which caused, over large areas, shales to succeed limestones. Were the life alone considered, they might well be united in one period.

Since the Trenton limestones extend widely over the continent and are full of marine fossils, the land must have been covered as widely by the sea. The beds reach nearly to the Azoic on the north, and hence the coast-line from New York westward was situated but little south of its position in the Azoic period. (See maps, pp. 136, 170.) And it is probable, from the occurrence of the rocks in the Winnipeg basin, that this line, bending northward near Lake Superior, followed the western border of the Azoic towards the Arctic.

The general absence of shales, even along the northern border as well as the Appalachian region, can be accounted for only on the supposition that the ocean had not free access from the eastward over the continent. The interior was probably in the condition of the lagoon or inner basin of a coral island. A barrier produced by the slight emergence of some part of the Atlantic border would have caused such a condition of the continent; and less than ten feet of elevation would have been sufficient,—for no more is needed in the islands of the Pacific. Its breadth may have varied from scores of miles to only a few rods. To the south, the waters probably opened (as they did afterwards) into the Gulf of Mexico: a connection with the ocean was necessary for their purity.

It is possible that this barrier, or reef, extended along the present position of the Green Mountains; but to the south, in Pennsylvania and Virginia, it must have lain to the eastward of the Appalachian region, since the Trenton rocks in part constitute that portion of the chain. The depth of water may have been small, if we judge from what is necessary for the formation of such limestones at the present day. Any subsidence in progress during its formation must have been exceedingly slow,—less than half an inch a year; for otherwise the animals forming the limestones out of their shells would have been destroyed by being sunk below the depth at which they could live. There was, beyond doubt, such a slowly-progressing subsidence; and in the Appalachians it exceeded in the end near 6000 feet (the thickness of the Trenton limestones), while over the interior it was, in general, not far from 300 feet.

The great St. Lawrence bay about Ottawa still existed, as in the Potsdam period, though probably somewhat contracted in size. (Map, fig. 205.) Here the subsidence must have been nearly 1000 feet.

The thin layers of shale in the Trenton limestone are no more than would have naturally been formed by streams flowing from the northern Azoic.

But with the opening of the Hudson period shales were formed in Canada and from the Hudson River westward along the northern border of the United States. They have their greatest thickness to the eastward, where they extend from Canada and New York southwest, along the Appalachian region; but over the middle of the interior basin, limestones (though often somewhat mixed with shales) were still in progress. It is evident that some great change had taken place. Probably the subsidence along the northern border of the United States (south of the Canada Azoic), and also along the Appalachian region, had been increased in rapidity, until the forming limestone reefs were submerged and the animals about them destroyed,—thus putting an end to the further increase of the calcareous beds, and leaving them as the foundation for future deposits. (A subsidence of the coral islands of the Pacific of 300 feet would wholly extinguish the life of the reef-forming corals.) The eastern continental barrier may also have been partly submerged, so as to admit the tidal and great oceanic currents, while other parts of it were just washed by the waves which swept from it and bore westward the finer detritus for portions of the Hudson River shales. Had the waves of the ocean entered in full force, beds of pebbles would have been more common among the deposits. Wherever the layers are somewhat arenaceous and full of

unbroken fossils, there may have been shallow waters and a muddy bottom, as with existing oyster-banks; where there are fine shales with few fossils, or a profusion of Graptolites, the depth was probably somewhat greater,—for currents carry fine material farthest from the shore-line; or there may have been sheltered bays, where gentle trituration would have produced the finest silt.

The Hudson River shales crossing New York east of Lake Ontario, and those of Canada west of this lake, follow so exactly the same course that we conclude with reason that the depression of the lake had not then been formed.

Over the interior of the Mississippi basin, away from the subsiding regions, the Trenton condition of the seas may, for the most part, have continued; and hence the continuation there of the limestone formations through the Hudson period.

The limestones of Anticosti Island, in the Gulf of St. Lawrence, afford definite proof of an eastern geological basin or area, as Logan has remarked. We have already spoken of this area (including St. Lawrence bay and the region southwest, with part of New England) as having to a great extent an independent geological history; and we shall soon have occasion to allude to it again. It will be observed that the limestones of Anticosti, if of the Hudson period, were in progress while the Hudson River shales were depositing over a considerable part of the United States.

As in the Potsdam period, the deposits of limestones and shales had their greatest thickness along the Appalachian region. The region, therefore, must have continued to be one undergoing great changes of level, in which the amount of subsidence was very large.

Climate.—No proof that a diversity of zones of climate prevailed over the globe is observable in the fossils of the Trenton or Hudson period, or of any part of the Lower Silurian era, as far as yet studied. The following species, common in the United States, and occurring at least as far south as Tennessee and Alabama, have been found in the strata of northern North America, near Lake Winnipeg:—*Strophomena alternata, Leptæna sericea?, Maclurea magna, Pleurotomaria lenticularis?, Calymene senaria, Chætetes Lycoperdon, Receptaculites Neptuni.*

The mild temperature of the Arctic is further evident from the occurrence of the following United States and European species at the localities mentioned on page 207:—*Chætetes Lycoperdon, Orthoceras moniliforme* H., *Receptaculites Neptuni* De France, *Ormoceras crebriseptum* H., *Huronia vertebralis* Stokes; besides *Maclurea Arctica* Haughton, near the Chazy species *M. magna.* Moreover, the formation of thick

strata of limestone shows that life like that of lower latitudes not only existed there, but flourished in tropical profusion.

Life.—*Exterminations.*—The Chazy epoch, the commencement of the Trenton period, opened with a new fauna, wholly distinct in species from that which preceded it. At its close these species, with few exceptions, disappear, and the Trenton epoch begins with an independent life. No facts have been observed to explain the nature of the catastrophe that intervenes between the two epochs. Such a fact as this—that sinking the coral islands of the Pacific three hundred feet would destroy the reef-forming Corals of those islands—may have some bearing on the subject. The geographical changes introducing the Hudson period appear to have had some connection with the partial destruction of the Trenton species that then occurred. A large number of species are continued on from the Trenton into the Hudson period wherever the rocks of the latter, like those of the former, are limestones. But where the latter are shales,—that is, wherever the great geographical change alluded to took place, which we have suggested may have been a subsidence destructive to the life,—there the species were almost wholly changed, and a new fauna appeared, and one fitted for the muddy bottom, and, therefore, including many Conchifers with the Brachiopods, and but few Crinoids.

With the close of the Trenton period there was nearly a total extinction of all the existing species throughout the great interior continental basin and the Appalachian region. Not over eight or ten species are known to have survived through the changes that followed introductory to the Upper Silurian. In the eastern border basin, at Anticosti, a much larger number of species continued on,—at least thirty; and there, as is explained beyond, limestones still had uninterrupted progress, while fragmental rocks spread largely over the rest of the continent.

The number of Lower Silurian species that are known to have become extinct in the American seas from the beginning of the Potsdam to the end of the Hudson period is about 850; and, adding 400 for undescribed species (which is not too large an addition), the whole number will be about 1250. (Billings.)

Many genera also disappeared in this time; and some of them are enumerated in connection with the observations on the Potsdam period. Among Mollusks, the genus *Maclurea*, containing large species, is one of the most prominent. But, besides genera, a whole family, in the case of the *Graptolites*, approaches its extinction. These species have their commencement and culmination in the Lower Silurian. Nearly all the genera of *Cystideans* also become

extinct. This singular type of Crinoids had its climax in the Lower Silurian, though not its final extinction. After this its species were few; while there is a great increase of Crinideans.

The number of Lower Silurian species known to have become extinct in Great Britain is about 600, and in Bohemia, according to Barrande, 300.

Thus far in American Geology, no evidence has been detected of (1) fresh-water lakes or deposits, or (2) of land or fresh-water life. The living species had been mainly Molluscan and Radiate, because these are the water-types in the Animal kingdom. And with them were associated the water-divisions of Articulates,—Worms and Crustaceans; but not yet the water-division of Vertebrates,—Fishes. The world had been populated solely by Mollusks and Radiates, Worms and Trilobites. The continent was, like its species, submarine in its mode of existence. It was already outlined, and in its heavings and progressing changes its coming features were shadowed forth,—even the Appalachian chain, and the great lakes,—although the mountains had not yet a foot of their present height above the seas, nor the lakes more than the beginnings of their depressions.

DISTURBANCES CLOSING THE LOWER SILURIAN ERA.

The strata of the Lower Silurian in North America appear to have been spread out over the Interior Continental basin in horizontal beds of great extent, and to have followed one another without much disturbance of the formations,—that is, no upturning that exposed outcropping edges to be overlaid by later horizontal deposits, producing thereby *unconformability*. In the Potsdam period there were local eruptions of trap in the region of Lake Superior; but no positive evidence of dislocations during the Lower Silurian era is yet known. The period that witnessed the gradual accumulation along the Appalachian region of 15,000 feet of deposits, we are sure, was *long;* and the more remarkable, therefore, is this exemption from catastrophe. Yet there is no doubt of extended oscillations in the water-level over the continental area. The rocks have afforded clear evidence of an indefinite range of shallow waters and sand-flats throughout the great interior in the Potsdam period; of somewhat deeper waters over the same wide area in the Trenton period, and such a uniformity of moderate depth as admitted of the formation of limestones of continental extent; then of other changes of level in the Hudson period,

which made shales, fine and coarse, to succeed, and alternate in the interior with other limestones. But the changes of level in these oscillations, although so great along the Appalachian region, were but gentle movements in the thin crust of the globe; and they may have been partly oceanic as well as continental; for the water-level along the continents would sink whether there were a downward movement or sinking in the bed of the ocean, or an upward bending of the land. But after the Hudson period there were greater changes, attended with violence; and the rocks and country bear marks of that violence,—probably more than have yet been distinguished.

In British America, near Gaspé, on the Bay of St. Lawrence, according to Logan, the Lower Silurian lies in tilted strata beneath beds of the Upper Silurian,—showing that an upturning had occurred before these superior beds were formed. Similar facts have been observed at the eastern base of the Green Mountains, where limestones of Upper Silurian and Devonian age rest unconformably on the altered strata of the Quebec group; and at Montreal, where the Lower Helderberg overlies unconformably the Hudson beds. The origin of the Champlain valley has been referred by Logan to the epoch closing the Lower Silurian.

The following section (fig. 356) has been published by Logan, in illustration of the fault, in the Appalachian series, in the vicinity of the Falls of Montmorency, just east of Quebec. It extends from the Montmorency side of the St. Lawrence across the north channel and the upper end of the island of Orleans.

Fig. 356.

F is the fault; 1, Azoic gneiss (Laurentian of Logan); 3, Trenton limestone overlying the Azoic; 4 *a*, Utica shale, and 4 *b*, Hudson River shale; 2, the Quebec group; S, S, the level of the sea; M, the position of Montmorency; C, the North Channel; O, Orleans Island. The horizontal and vertical scale is one inch to a mile. "The channel of the Montmorency is cut through the black beds of the Trenton formation to the Laurentian gneiss on which they rest, and the water, at and below the bridge, flows down and across the gneiss, and leaps at one bound to the foot of the precipice, which immediately behind the water is composed of this rock." The Trenton limestone at the top of the precipice is fifty feet thick and nearly horizontal; at the foot of the precipice it lies against the gneiss of nearly the same thickness, but dipping at an angle of 57°, and is overlaid by shales with some sandstone of the Utica formation.

The Quebec group (Calciferous epoch) and the beds of the Trenton and Hudson periods are represented as having been originally laid down in conformable strata, and as having been involved together in the folding and faulting here illustrated.*

In Pennsylvania, also, according to H. D. Rogers, the Upper Silurian beds of the Kittatinny Mountain lie unconformably on the upturned Lower Silurian.

In Tennessee, according to J. M. Safford, there is an area some eighty miles in diameter, about the centre of the State, which was probably raised above the ocean at this same epoch; for, *first*, the next bed of rock covering it is a shale of the Upper Devonian, the Upper Silurian and all the Lower Devonian being absent; and, *secondly*, the absent rocks, where they appear around the area, thin out towards it, while there is no evidence that denudation was the cause.

In Ohio, about Cincinnati, there is a large region where the Lower Silurian strata are surface-rocks, owing to an uplift; but it is not yet known whether this exposure was a consequence of a disturbance immediately after the formation of the beds, or whether there were subsequent Silurian and Devonian beds which have been removed by denudation.

Besides these changes, there was also a general increase of dry land along the northern border of the United States and through Canada. The broad band of Hudson River shales shown on the map (p. 170) must have been left to a great extent exposed by an uplift; for the next deposits do not cover it, and it is not probable that they ever did. The dry land of the continent was gradually expanding southward, and at the commencement of the Lower Silurian its outline in New York lay to a considerable distance south of the Mohawk River.

Moreover, the great St. Lawrence gulf about Ottawa, where the Trenton and Hudson formations had been accumulated, was probably nearly obliterated at this time; for no rocks of more recent date occur there, to prove the presence of the sea, until the Post-tertiary period, just before the Age of Man, excepting the small patch of Lower Helderberg near Montreal. This region of dry land spread eastward from Montreal to the Appalachian region in Vermont, which region also was probably above the water-level. Thus, the St. Lawrence channel, which was first a short strait between the Azoic areas of Canada and New York, had become much narrowed and lengthened by the close of the Lower Silurian; but it still opened into a broad oceanic basin near the longitude of Quebec; for both Upper Silurian and Devonian strata were formed over eastern Canada and a large part of New

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* These facts and citations are from the paper of Sir William Logan, published in the Canadian Naturalist and Geologist, 1861, and also the Amer. Jour. Sci. [2], xxxiii.

England. The eastern half of Vermont, as the rocks show, lay within the submerged area; and hence the emergence of the western (or Appalachian) portion had been small. Lake Champlain was probably defined as a long, narrow bay or arm of the St. Lawrence sea.

The disturbances opening the era of the Upper Silurian were followed, if not attended, by the formation of a coarse conglomerate along the Appalachian region, which is described beyond. There was also, as has been remarked, a nearly complete extermination of the living species over the continent.

In Europe there was also a period of disturbance at the close of the Lower Silurian; but the destruction of life was less complete than over central North America, and corresponds nearly with that in the eastern basin about the Gulf of St. Lawrence.

There is evidence of unconformability between the Upper and Lower Silurian in some parts of England, and the elevation of the Westmoreland Hills, as first ascertained by Professor Sedgwick, has been referred to this epoch; so, also, that of the mountains in North Wales, and hills in Cornwall, and the range of southern Scotland from St. Abb's Head, on the east coast, to the Mull of Galloway. Elie de Beaumont refers to this era the elevation of the Hundsruck Chain (now about 3000 feet high) and other ridges in Nassau. The changes of the period are supposed to have been attended in England by metamorphic action, in which gneiss and clay slates were made out of the Lower Silurian deposits by some process dependent probably in part upon the escaping heat of the epoch of disturbance.

B. UPPER SILURIAN.

Marine life, large oceans, small lands, and warm climates—the features of the Lower Silurian—continued to characterize the opening period of the Upper Silurian.

The periods and epochs indicated in the New York rocks have been mentioned on p. 168. The periods are—the NIAGARA (5), the SALINA (6), and the LOWER HELDERBERG (7).

1. NIAGARA PERIOD (5).

Epochs.—1. ONEIDA epoch, or the epoch of transition between the Lower and Upper Silurian, when the Oneida conglomerate (5 *a*) was formed; 2. MEDINA epoch, or that of the Medina sandstone

(5 *b*); 3. CLINTON epoch, or that of the Clinton group (5 *c*); 4. NIAGARA epoch, or that of the Niagara shale and limestone (5 *d*).

1. ONEIDA EPOCH (5 *a*).

I. Rocks: kinds and distribution.

In the *Interior Continental basin* there are no Oneida rocks, except in its northeastern corner. The Oneida conglomerate (5 *a*, map, p. 170) is the surface-rock in central New York, in Oneida and Oswego counties, and west to Lake Ontario, lying just south of the outcropping Hudson River beds. It is 20 to 120 feet thick in this region. Going eastward, it disappears, being very thin in Herkimer co., and not occurring at all in the Helderberg Mountains south of Albany. In the Appalachian region it has great thickness. In the Shawangunk Mountains, in southeastern New York (which are within this region), the rock is nearly 500 feet thick, and is called the Shawangunk grit. It is still thicker to the southwest, in Pennsylvania, being 700 feet thick in the Kittatinny valley. It continues on through Virginia, following the course of the Appalachians.

The rock is a hard, gritty conglomerate or sandstone, of a grayish color, made of rounded quartz pebbles and sand, or of coarse sand alone, very firmly cemented. It is so rough in surface as to serve for millstones: the Esopus millstones are made of it. The firmness of the rock contrasts strikingly with the loose texture of the Medina sandstones.

In the *Eastern border region*, at Anticosti, there are no signs of the Oneida conglomerate; but, instead, the limestones referred to the Hudson period are followed uninterruptedly by other limestones, which are continued even into the Clinton epoch; and in this case the Oneida epoch has probably some representation among the beds. But it is more probable, according to recent investigations, that these limestones are wholly Upper Silurian, and belong to the following epochs of the Niagara period.

In the Shawangunk Mountains there are two systems of joints, trending S. 20° W. and S. 60° E. (Mather). The Ulster lead and copper mine near Redbridge is situated in this rock: it has afforded large masses of galena and copper pyrites, with blende, but is not worked. The Ellenville and Shawangunk mines are others of similar character in the grit.

II. Life.

The only known fossils are *Fucoids* (Sea-weeds) and a few imperfect, undetermined shells. One of the Fucoids resembles the

Fucoides (*Arthrophycus*) *Harlani*, fig. 358,—a very common fossil in the Medina sandstone. It suffices to prove that the Oneida epoch is more closely related to that following than to the preceding, and hence belongs to the *Upper* Silurian era.

2. MEDINA EPOCH (5 *b*).

I. Rocks: kinds and distribution.

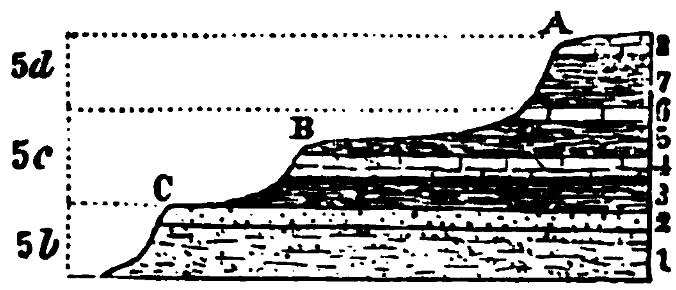
In the *Interior Continental basin* the Medina formation is not known, excepting to the northeast. It occurs in western New York, overlying the Oneida conglomerate; towards Utica it thins out, and is not known east of there. On the Niagara the beds have a thickness of 350 to 400 feet. It spreads northwest, and has been recognized as far as the Straits of Mackinac.

Along the *Appalachian region* it extends south through Pennsylvania and Virginia, where in some places the beds are over 1500 feet thick.

The rocks are argillaceous sandstones, and marls of red, gray, and mottled colors. The sandstones are thinly laminated, as is usual when much argillaceous, and in general are quite fragile.

In the *Eastern border region*, at the island of Anticosti, just north of Nova Scotia, limestones follow those referred to the Hudson period, without interruption; the strata, according to the description in Logan's Canadian Report, have a thickness—reckoning from the top of the beds of the Hudson period, up to those which are regarded of the Clinton epoch which follows the Medina—of 700 feet; they are said to contain about thirty species of fossils common to the Lower and Upper Silurian, and are described as beds of passage between the two eras; but according to Shaler, all the beds of the limestone formation are Upper Silurian.

Fig. 357.



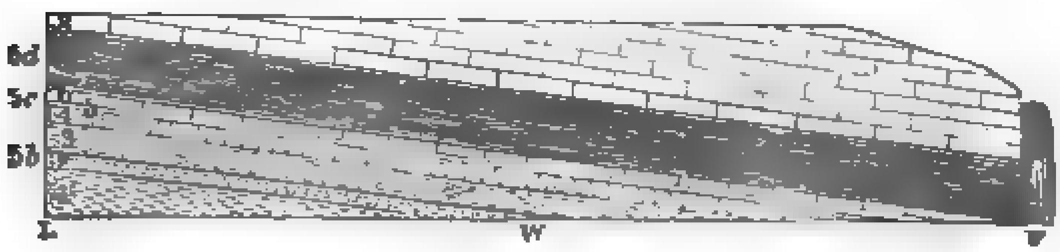
Section at Genesee Falls.

The relation of the Medina group to the overlying Clinton and Niagara groups is well illustrated in one or two sections from the western part of the State of New York. Fig. 357 represents the rocks at Genesee Falls, near Rochester. The lower strata, 1, 2, are the Medina sandstone (5 *b*); 3, 4, 5, 6, the Clinton group (5 *c*); and 7, 8, the Niagara group (5 *d*),—2 being a grit rock, 3 and 5 shales, 4 and 6 limestone, 7 shale, and 8 limestone. The whole height is about 400 feet.

The following figure (357 A) represents a section of the rocks along Niagara River, from the bluff at Lewiston (L) to the Falls at F, passing by the Whirlpool at W,—a distance of seven miles.

In the beds at Lewiston there are *eight* strata: 1, 2, 3, 4, belong to the Medina group, and consist—1 and 3, of shaly sandstone; 2 and 4, of hard sandstone; 5, a shale, and 6, limestone, are of the Clinton group; 7, a shale, and 8, limestone, of

Fig. 357 A.



Section along the Niagara, from the Falls to Lewiston Heights.

the Niagara group. The dip is up-stream, as in the figure, but is only fifteen feet to a mile.

Where fullest developed in New York, the Medina group includes four divisions, as follow:—

4. Red marl or shale, and shaly sandstone, resembling No. 2, below; banded, and spotted with red and green.

3. Flagstone,—a gray, laminated quartzose sandstone, called "gray band."

2. Argillaceous sandstone and shale, red, or mottled with red and gray.

1. Argillaceous sandstone, graduating below into the Oneida conglomerate.

In the Genesee section (fig. 357) the strata 1 and 2 correspond to 2 and 3 of these divisions; and the Niagara section contains 2, 3, and 4.

Structural peculiarities.—The beds bear evidence of having been formed as a sand-flat or reef-accumulation. Besides the thin lamination alluded to, they abound in ripple-marked slabs (fig. 62); mud-cracks (figs. 64, 65), due to sun-drying; wave-lines; rill-marks about stones and shells (fig. 63); and diagonal lamination (fig. 61 *e*), an effect of tidal currents. Fig. 63 is drawn from a slab of Medina sandstone. All these peculiarities evince that the accumulations, while forming, were partly in the face of the waves and currents, and partly exposed above the waves to the drying air or sun and to the rills running down a beach on the retreat of the tides or waves.

II. Life.

1. *Plants.*

Sea-weeds are common, and especially the Fucoid *Arthrophycus Harlani* (fig. 358). The stems are transversely furrowed, and look a little as if jointed,—to which peculiarity the name alludes (from *αρθρον*, *a joint*, and *φυκος*, *fucus*, a kind of leathery sea-weed).

2. *Animals.*

The arenaceous and shaly character of the beds is unfavorable for *Radiates*, and only a rare coral or Crinoidal fragment has been met with.

Figs. 358–363.

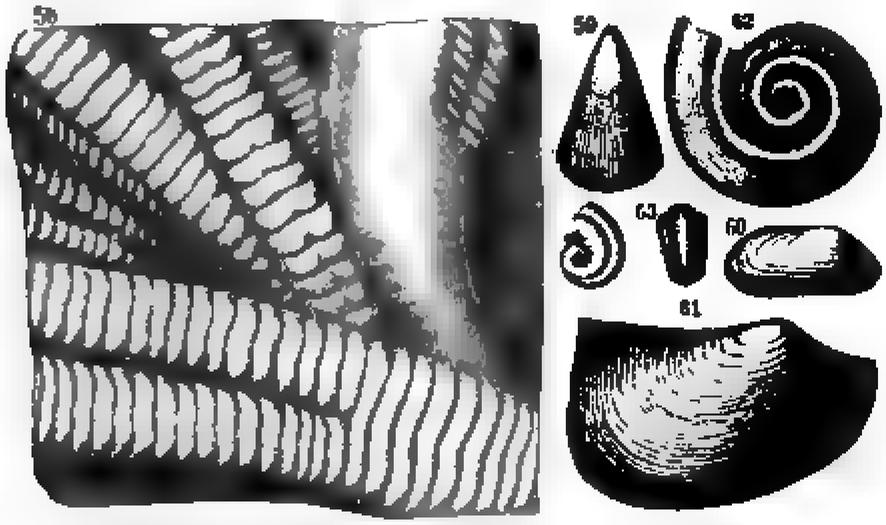


Fig. 358, Arthrophycus Harlani; 359, Lingula cuneata; 360, Modiolopsis orthonota; 361, M.? primigenius; 362, Pleurotomaria litorea; 363, Bucania trilobata.

Of *Mollusks*, the most common species is the Brachiopod *Lingula cuneata* (figs. 359 and 63), which sometimes thickly covers large surfaces, and is a good mark of the epoch.

Among the few other species there are the following:—Fig. 360, *Modiolopsis orthonota*; 361, *M. ? primigenius*, 362, *Pleurotomaria litorea* H.; 363, *Bucania trilobata*, different views. *Orthocerata* are occasionally met with.

The only Crustacean described is the Ostracoid *Leperditia cylindrica*.

The Medina epoch is closely related in its rocks and fossils to the Clinton epoch.

3. CLINTON EPOCH (5 *c*).

I. Rocks: kinds and distribution.

The Clinton rocks have a wide range over the country. In the *Interior Continental basin* they fail in New York on the Hudson; but, commencing near Canajoharie, they stretch westward across the State beyond Lake Ontario, through Canada. They occur farther west, in Michigan, Ohio, and the States west, to the Mississippi, and perhaps also beyond the Mississippi, in Iowa. The formation is 200 feet thick in some parts of New York; to the west it is very thin, and in the States bordering on the Mississippi it is seldom recognizable.

In the *Appalachian region* the strata have been observed in Penn-

sylvania, Virginia, and Alabama. The thickness in the first of these States is in some places 2000 feet.

The rocks in New York and along the northern border of the United States are mostly shaly sandstones or flags and shales, with some layers of limestone. But in the Michigan peninsula, and to the south, limestone predominates.

The sandstone is often quite hard, and much of it has the surface uneven from knobby and vermiform prominences, some of which are due to Fucoids.

In many regions, as in central New York, Ohio, and Wisconsin, there are one or more thin beds of red argillaceous iron-ore, called *lenticular ore*, from the small flattened grains which compose it.

In the *Eastern border region*, at Anticosti Island, the limestones of this period are several hundred feet thick. Shales with limestone occur in northern Nova Scotia.

a. Interior Continental basin.—On the Genesee (see fig. 357, p. 231), the Clinton group consists of,—

(1.) 24 feet of *green shale*, of which the lower part is shaly sandstone and the upper part an *iron-ore* bed; (2.) 14 feet of limestone, called *Pentamerus limestone* from a characteristic fossil; (3.) 24 feet of *green shale*; (4.) 18½ feet of limestone, called the *upper limestone*.

On the Niagara (see section, fig. 357 A, p. 232), there is only a shale 4 feet thick, *without* the iron-ore, overlaid by a limestone stratum 25 feet thick,—this limestone corresponding to the three upper divisions, and its upper 20 feet to the upper limestone. To the eastward, in Oneida, Herkimer, and Montgomery counties, the rock is 100 to 200 feet thick, and includes no limestone, though partly calcareous. The group consists of shale and a hard grit or sandstone in two or more alternations, along with two beds of the lenticular iron-ore. The flattened grains making up this ore are concretions like those of an oolite. Near Canajoharie—which is not far from its eastern limit—the formation has a thickness of 50 feet. In the town of Starkville, Herkimer co., the rock contains a good bed of gypsum.

In Ohio, the Clinton group is recognized by its Fucoids, overlying the Blue limestone of Cincinnati. In Wisconsin, the bed of lenticular iron-ore is 6 to 10 or even 15 feet thick.

In Michigan, south of Lake Superior, and about the northeastern shores of Lake Michigan, the rocks are limestone with hard sandstones and shales like those of central New York. The thickness in the peninsula is 51 feet.

b. Appalachian region.—In Pennsylvania, Professor Rogers divides the rock into (1) a lower slate, which at Bald Eagle Mountain is 700 feet thick; (2) iron-sandstone, 80 feet in the Kittatinny Mountain; (3) upper slate, 100 to 250 feet; (4) lower shale, 100 to 250 feet; (5) ore-sandstone, 25 to 110 feet; excepting the last, these strata augment in thickness to the northwest; (6) upper shale, 120 to 250 feet, which thickens to the northwest; and (7) red shale or marl, 975 feet thick, at the Lehigh Water-Gap. The formation spreads across the State "from the northwest flank of the Kittatinny Mountain to the similar

slope of the last main ridge of the foot of the Alleghany Mountains." (H. D. Rogers.)

c. *Eastern border region.*—The total thickness of the series of limestones at Anticosti is 1344 feet. Of this, 734 feet have been supposed to "show a passage from the Upper to the Lower Silurian." (J. Richardson, in Logan's Report.) But according to Shaler, the whole series belongs to the Upper Silurian, and it extends into the Niagara epoch.

In Nova Scotia, as described by Dawson, the strata occur on the northern coast. At Arisaig, where the rocks are shales and limestone and have a thickness of about 500 feet, fossils occur through the formation and are very abundant in the upper or more calcareous part. At the East River of Pictou there are also slates and calcareous bands, probably of this epoch. They include a deposit of oolitic iron-ore, like that of the Clinton rocks of central New York, which in some places has a thickness of 40 feet.

South of the St. Lawrence, Clinton beds occur on the river Chotte.

II. Life.

The rocks of the Oneida and Medina epochs, as they afford but few fossils, give no assurance that the waters had been fully resupplied with life after the destruction that closed the Lower Silurian. But in the beds of the Clinton epoch fossils again abound, and the Niagara strata, which follow, bear full testimony to a populous globe.

1. *Plants.*

Great numbers of *Fucoids* occur in the Clinton beds of central New York, differing from those below. They are of various diameters, from the size of a finger and larger to that of a thread.

Fig. 364.

Rusophycus bilobatus.

One of the most characteristic species is represented in fig. 364. No traces of land-plants are known.

2. *Animals.*

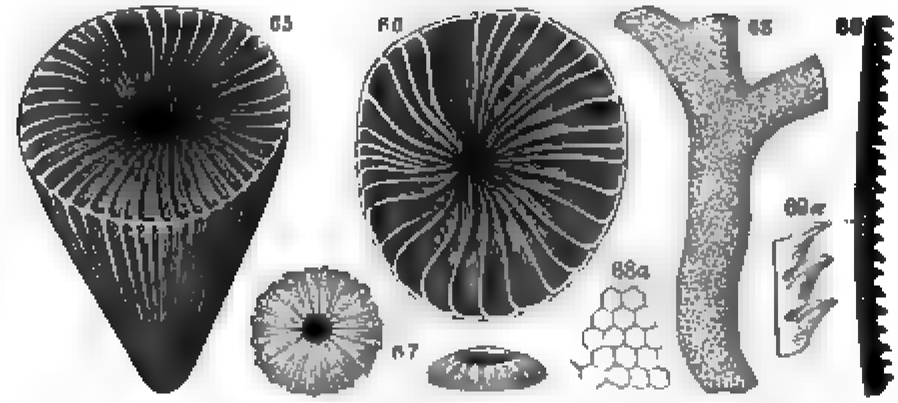
Many of the limestones were coral reefs, and abound in corals, a few of which are represented in figs. 365–368. Graptolites (figs. 369, 369 *a*) continue in the waters over the muddy bottoms, but the genus here became extinct. Brachiopods were common: among them the genus *Pentamerus* has here its earliest species, and *P. oblongus* (fig. 371) was especially abundant. The tracks of some of the Mollusks are found on some layers. Fig. 381 is a portion of one, reduced one-half: it resembles the track made in the mud by some Unios. Fig. 382 represents what is supposed to be the

trail of a sea-worm, or Annelid, reduced one-half. There were also Orthocerata and Trilobites.

Characteristic Species.

1. **Radiates.**—(*a.*) *Polyps*.—Figs. 365, 366, *Zaphrentis* (*Caninia*) *bilateralis*; 367, *Palæocyclus rotuloides*, different views, from New York; 368, a branching

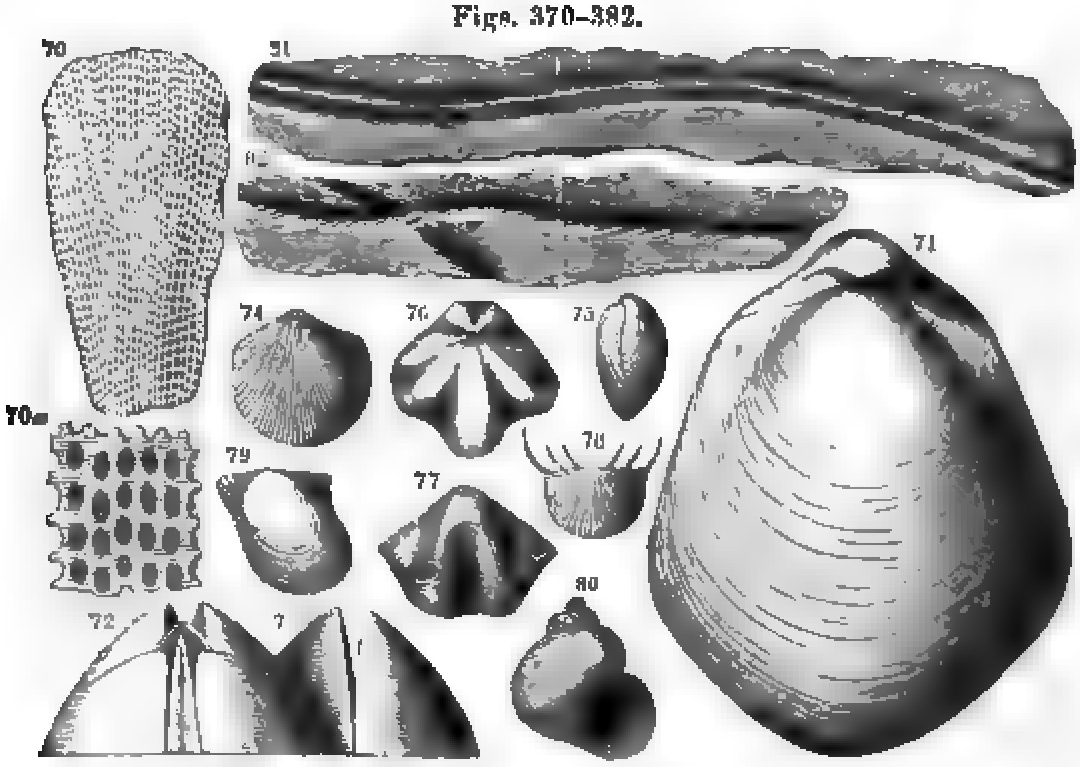
Figs. 365–369.



RADIATES.—Figs. 365, 366, Zaphrentis bilateralis; 367, Palæocyclus rotuloides; 368, *a*, Chætetes; 369, *a*, Graptolithus Clintonensis.

Chætetes. (*b.*) *Acalephs*.—369, *a*, *Graptolithus Clintonensis*. (*c.*) *Echinoderms*: *Crinoids*.—A few species are known: fragments are common, and they are often found in the iron-ore as well as in the limestones.

Figs. 370–382.



MOLLUSKS.—Figs. 370, *a*, Fenestella? prisca; 371, Pentamerus oblongus; 372, 373, part of casts of the interior, 374, 375, Atrypa reticularis; 376, 377, Athyris (formerly Atrypa) congesta, 378, Chonetes cornuta; 379, Avicula rhomboidea, 380, Cyclonema cancellata; 381, track of a Bivalve (× ½); 382, track of an Annelid? (× ½).

2. **Mollusks.**—(*a.*) *Bryozoans*.—Fig. 370, *Fenestella? prisca*.

(*b.*) *Brachiopods.*—There are species of Lingula, Orthis, Leptæna, Rhynchonella, Spirifer, and also of the new genera for America, *Chonetes* and *Pentamerus.* Fig. 371, *Pentamerus oblongus;* some specimens are more than twice the size of this figure, and very thick; it is abundant in New York State and the West, and occurs also in Britain; figs. 372, 373 show casts of the interior,—372 a dorsal view, and 373 a ventral. Figs. 374, 375, *Atrypa reticularis,* or a related species; the *A. reticularis* is reputed to extend through the Niagara period into the Hamilton of the Devonian; but more than one species are probably here included; this also is a foreign species: it is one of the few species of true Atrypa; the interior of the shell is shown in fig. 215. Fig. 376, *Athyris ? congesta;* fig. 377, same, different view,—it has a spire within, extending downward and outward; fig. 378, *Chonetes cornuta* Koninck.

(*c.*) *Conchifers.*—Fig. 379, *Avicula rhomboidea* H.

(*d.*) *Gasteropods.*—Fig. 380, *Cyclonema cancellata* H. *Bucania trilobata* of the Medina also occurs here, besides other Univalves.

(*e.*) *Cephalopods.*—There are a few *Orthocerata.*

3. **Articulates.**—Remains of Trilobites of the genus *Homalonotus,* and of the same species figured under the Niagara epoch. Tracks or scratches occur which have been referred with good reason to Crustaceans, besides others like fig. 382, that are attributed to Worms.

Among the Clinton species are the following from the Lower Silurian:—*Orthis Lynx, Leptæna sericea, Bellerophon bilobatus.* The following are known in Europe:—*Orthis Lynx, Chonetes cornuta, Atrypa reticularis, A. hemispherica, Spirifer radiatus, Pentamerus oblongus.*

NIAGARA EPOCH (5 *d*).

I. Rocks: kinds and distribution.

The Niagara and Clinton epochs had several points of similarity. (1.) The formations thin out to the eastward in New York. (2.) The rocks are shales and limestone, but the latter increases in proportion in central and western New York, and becomes the prevailing material of the formation through the interior of the Mississippi basin, while along the Appalachians in Pennsylvania and farther south the rocks are almost solely shales. (3.) A considerable number of the Clinton fossils reach up into the Niagara formation.

On the contrary—(1.) The Niagara beds spread more widely over the continent,—occurring through a large part of the *Interior Continental basin,* from New York to beyond the Mississippi, and from Michigan to Tennessee, as well as along the *Appalachian region* in Pennsylvania and Virginia to Alabama; also at various places in the *Arctic,* and in other parts of British America, as on the borders of Hudson Bay. (2.) The great majority of the species are not found in the Clinton beds, and the species are more generally clear-

water species, as Corals and Crinoids. (3.) The Niagara epoch was eminently one of the *limestone* epochs of the American Silurian.

The limestones are usually made up of fossils, and are often magnesian. In western New York, near Niagara Falls, there are 165 feet of limestone (directly at the Falls, 85 feet) overlying 80 of shale (fig. 357 A); and the undermining of the limestone by the falling waters, which readily remove the shale, is the occasion of the slow retrocession of the Falls. Along the Appalachian region in Pennsylvania, the beds have a thickness exceeding 1500 feet,—thus, like the earlier formations, surpassing many times in extent the beds of the interior basin.

a. Interior Continental basin.—At Rochester, N.Y., there are about 80 feet of limestone, overlying 80 of shale. Farther eastward, in Wayne co., the limestone is 30 or 40 feet thick, and in Cayuga co. still less. The formation thins out altogether in Herkimer co.

In the States west of New York the limestone lies directly upon the Clinton limestone. In the peninsula of Michigan the thickness is about 100 feet (Winchell). In Ohio, Indiana, and Illinois, this rock and the Corniferous overlying it have been called the *Cliff-limestone*, because it often stands in bold bluffs along the river-valleys. Such bluffs are a common feature in all limestone regions where the strata are nearly horizontal and in heavy beds.

In the Helderberg Mountains there is a layer of limestone 25 feet thick, called *Coralline limestone*, which has been referred to the Niagara epoch. It has been suggested that it should be united rather with the overlying formation.

b. Appalachian region.—In Pennsylvania the formation consists of two distinct deposits of marl or fragile shale. The lower is about 450 feet thick where most developed, near the middle belt of the Appalachian zone, and decreases both to the southeast and northwest. The upper deposit is 1200 feet thick in the northwest belt, and declines to the southwest (H. D. Rogers). These strata may include, besides the true Niagara, strata of the Salina or Salt-group period.

c. Eastern border region.—The Niagara limestone is supposed to occur in eastern Canada some distance south of the St. Lawrence, in the course of a limestone belt running between northern Vermont and Gaspé on the gulf; but it has not yet been identified with certainty.

Near New Canaan, in Nova Scotia, there are clay slates of the Niagara epoch.

d. Arctic regions.—In the Arctic, the Niagara limestone has been observed between the parallels of 72° and 76° on the shores of Wellington and Barrow's Straits, and on King William's Island. The common Chain-coral *Halysites* (*Catenipora*) *catenulata* has been found at several localities, along with other Upper Silurian species. (See, further, p. 242.)

The color of the Niagara limestone is commonly dark bluish-gray to drab. It is sometimes quite impure, and good for hydraulic purposes. A specimen from Makoqueta, Jackson co., Iowa, afforded J. D. Whitney—carbonate of lime, 52.18, carbonate of magnesia, 42.64,—with 0.35 of carbonate of soda, a *trace* of

potash, carbonate of iron, chlorine, and sulphuric acid, 0.63 of alumina and sesquioxyd of iron, and 4.00 insoluble in acid,—making it nearly a true dolomite.

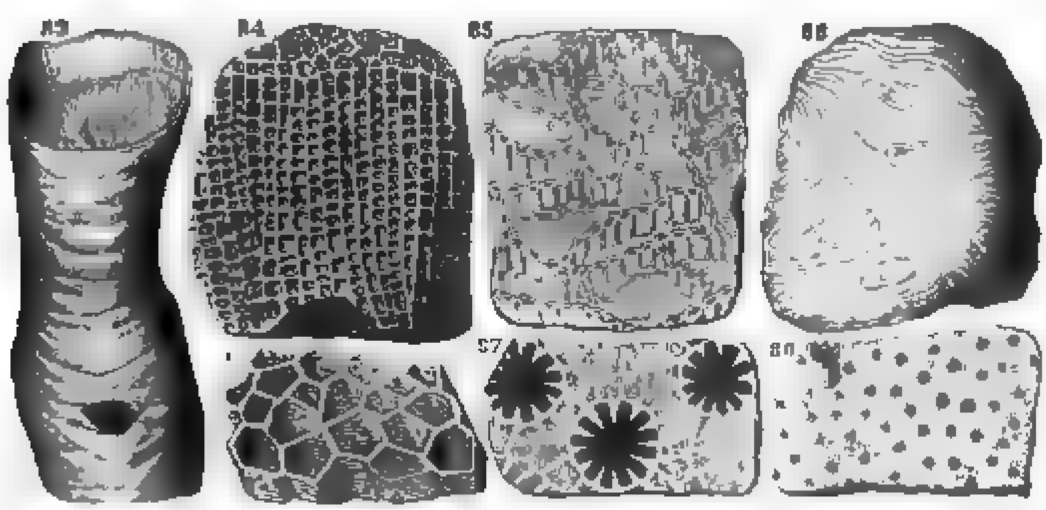
The structure of the limestone is often nodular or concretionary. In Iowa and some other parts of the West the rock abounds in chert or hornstone, which is usually in layers coincident with the bedding, like flint in chalk, and the fossils are all siliceous. At Lockport, N.Y., cavities in the limestone afford fine crystallizations of dog-tooth spar (calcite) and pearl-spar (dolomite), with gypsum, and occasionally celestine, and still more rarely a crystal of fluor. The limestone sometimes breaks vertically with smooth columnar surfaces,—a peculiarity which has been attributed to the crystallization of a foreign substance.

II. Life.

Corals and crinoidal remains are so abundant in the Niagara limestones, and, in many places, so far make up the rock, that the beds have been well called old coral reefs. The variety of life about the reefs was very great. We find, besides the flowering Corals and the slender-rayed Crinoids, great numbers of Brachiopods, some Conchifers, large Orthocerata, and many new kinds of Trilobites. There is no evidence of any fishes, and none of life over the land or in fresh waters.

Figs. 383–388 represent some of the Corals. Fig. 383, one of the Cup-corals; fig. 385, *Halysites catenulata*, projecting above the limestone in which it is imbedded,—it is often called *Chain-coral*, from the appearance in a transverse section; fig. 384, *Favosites Niagarensis*, a Coral of a columnar structure, with horizontal partitions in the cells. Three out of the many fine Crinoids are represented

Figs. 383–388.



CORALS.—Fig. 383, Chonophyllum Niagarense; 384, *a*, Favosites Niagarensis; 385, Halysites catenulata; 386, 387, Heliolites spinipora; 388, Stromatopora concentrica.

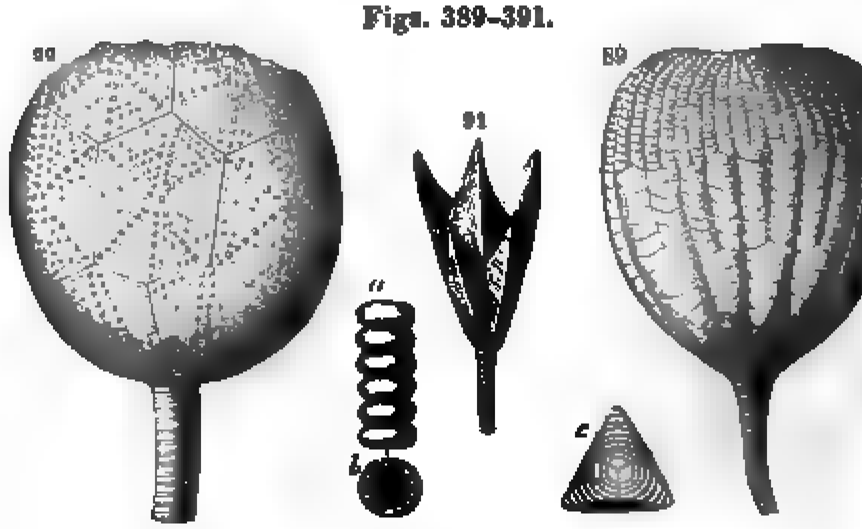
in figs. 389–391; Brachiopods, in figs. 392–404; Conchifers and Gasteropods, in figs. 405–407; Trilobites, in figs. 408–411. *Pentamerus oblongus* of the Clinton epoch (fig. 371) is abundant in the Niagara limestone of Wisconsin and Iowa.

Characteristic Species.

1. **Radiates.**—(*a.*) *Polyps* (Corals).—Fig. 383, *Chonophyllum Niagarense* (Conophyllum of Hall, a genus first published in 1852, two years after Chonophyllum by Edwards); 384, *Favosites Niagarensis*; 384 *a*, surface of same, enlarged, showing outline of cells; 385, *Halysites catenulata*; 386, *Heliolites spinipora* H.; 387, an enlarged view, showing the 12-rayed cells and the interval of a cellular character separating them, both of which are distinguishing characteristics of the genus Heliolites; 388, *Stromatopora concentrica*.

(*b.*) *Echinoderms.*—Fig. 389, *Ichthyocrinus lævis* Conrad, a species which is sometimes twice as large as the figure; 390, *Caryocrinus ornatus* Say, of Lockport, the nut-like shape having suggested the generic name (from *Carya*, the hickory-nut); 391, *Stephanocrinus angulatus* Conrad, of Lockport; *a*, part of the stem, enlarged; *b*, joint of the stem, top-view: *c*, base of the body, showing the three pieces of which it consists. Also, fig. 156 (page 148), the Cystid *Callocystites Jewettii* H., and fig. 154, the Star-fish *Palæaster Niagarensis*.

Figs. 389–391.



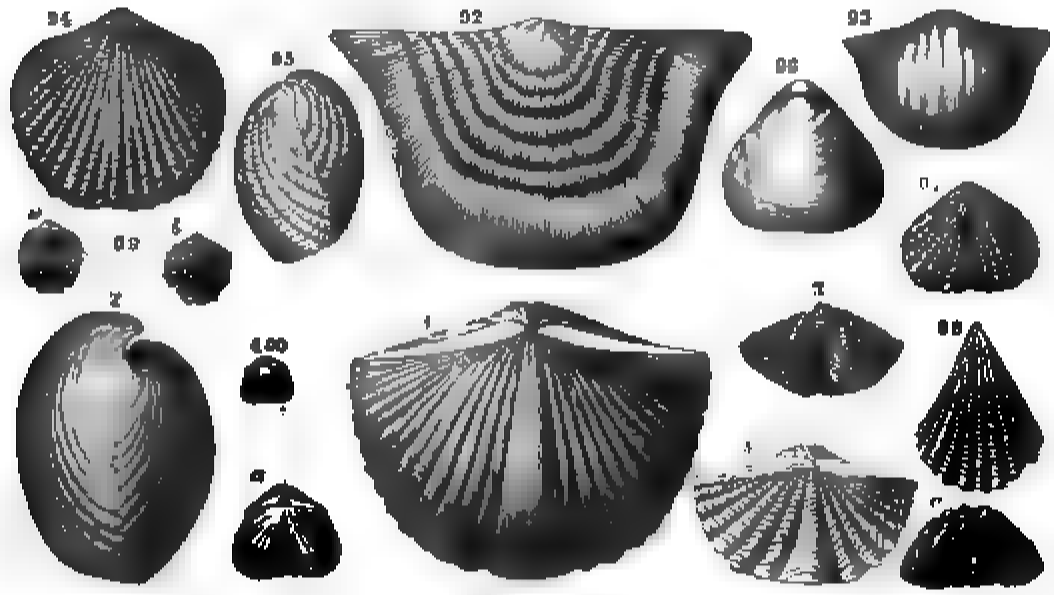
CRINOIDS.—Fig. 389, Ichthyocrinus lævis; 390, Caryocrinus ornatus; 391, *a*, *b*, *c*, Stephanocrinus angulatus.

2. **Mollusks.**—(*a.*) *Bryozoans.*—Many species of delicate corals of the genus *Fenestella*, resembling fig. 370, and of other genera. (*b.*) *Brachiopods.*—Fig. 392, *Strophomena rugosa*; 393, *Leptæna transversalis* Dalman; 394, *Atrypa nodostriata*, the Niagara form of this species; 395, same, side-view; 396, *Merista nitida*; 397, *Pentamerus interplicatus*; 398, *a*, *Rhynchonella cuneata*; 399 *a*, *b*, *Leptocœlia disparilis*; 400, *Orthis bilobus*; 400 *a*, same, enlarged; 401, *Spirifer Niagarensis*; 402, same, side-view; 403, 404, *Sp. sulcatus*. Among these, all but the *Leptocœlia disparilis*, *Atrypa nodostriata*, and the *Orthis* and *Spirifers*, are found also in European rocks.

(c.) *Conchifers*.—Fig. 405, *Avicula emacerata*.

(d.) *Gasteropods*.—Fig. 406, *Platyostoma Niagarensis*; 407, *Platyceras angu-*

Figs. 392–404.



BRACHIOPODS.—Fig. 392, Strophomena rugosa; 393, Leptæna transversalis; 394, 395, Atrypa nodostriata; 396, Merista nitida; 397, Pentamerus interplicatus; 398, *a*, Rhynchonella cuneata; 399, *a*, *b*, Leptocœlia disparilis, 400, *a*, Orthis bilobus; 401, 402, Spirifer Niagarensis; 403, 404, Sp. sulcatus.

latum, a true univalve, but loosely and imperfectly coiled, as shown in the profile view, fig. 407 *a*.

Figs. 405–407.

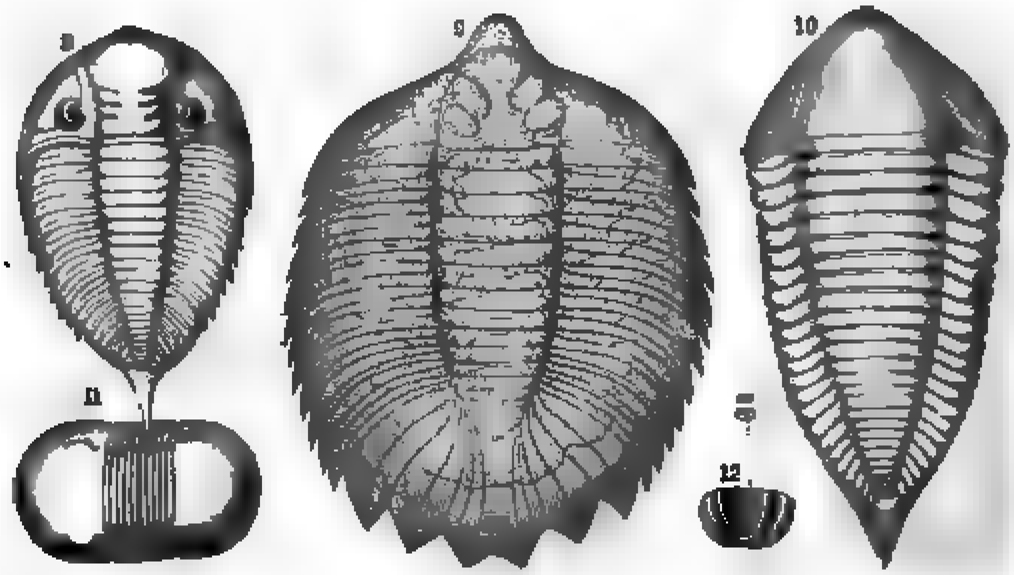
CONCHIFERS and GASTEROPODS.—Fig. 405, Avicula emacerata; 406, Platyostoma Niagarensis; 407, *a*, Platyceras angulatum.

(e.) *Cephalopods*.—Species of *Orthoceras*, *Cyrtoceras*, *Gomphoceras*, and of *Conularia*. The last probably belongs to the division of Cephalopods having *internal* shells.

3. **Articulates**.—(*a*.) *Trilobites*.—Fig. 408, *Dalmania limulurus* (a genus differing from Calymene in having the glabella, or middle region of the buckler, largest anteriorly, besides having large reniform eyes and other peculiarities); 409, *Lichas Boltoni*, a large and characteristic species, much reduced; 410, *Homalonotus delphinocephalus* (the genus having very small eyes, the glabella faintly outlined and undivided,—the middle lobe of the body much broader than the lateral); 411, *Illænus Barriensis*; *Calymene Blumenbachii* var. *Niaga-*

rensis, near fig. 177 (page 151). (*b.*) *Ostracoids*, or bivalve Crustaceans.—Fig. 412, *Beyrichia symmetrica*, showing one of the valves; *a*, same, natural size.

Figs. 408–412.



CRUSTACEANS.—Fig. 408, Dalmania limulurus (× ½); 409, Lichas Boltoni (× ½); 410, Homalonotus delphinocephalus (× ¼); 411, Illænus Barriensis (× ½); 412, Beyrichia symmetrica; 412, *a*, same, natural size.

The following are some of the species common to the Niagara and Clinton groups:—

Halysites catenulata (fig. 385).
Caryocrinus ornatus (fig. 390).
Hypanthocrinus decorus.
Lingula lamellata.
Orthis elegantula (fig. 329).
Strophomena rugosa (fig. 392).
Pentamerus oblongus (fig. 371).
Rhynchonella neglecta.
Atrypa reticularis (fig. 374).
Spirifer radiatus.
Avicula emacerata (fig. 405).
Orthonota curta?
Modiolopsis subalatus?
Ceraurus insignis.
Homalonotus delphinocephalus (fig. 410).
Calymene Blumenbachii.
Dalmania limulurus (fig. 408).
Illænus Barriensis (fig. 411).

According to Salter, a number of species of the Upper Silurian, and probably of this part of it, have been observed in the Arctic; as, *Halysites catenulata*, *Orthis elegantula*, *Favosites Gothlandica*, *Leperditia Baltica*, species of *Calophyllum*, *Heliolites*, *Cystiphyllum*, *Cyathophyllum*, *Syringopora*, with *Pentamerus Conchidium*, *Atrypa reticularis*, etc.; and at the southern extremity of Hudson's Bay, *Pentamerus oblongus*, *Atrypa reticularis*, etc. About Lake Winnipeg, also, Upper Silurian fossils have been found. See Am. Jour. Sci. [2], xxi. 312, xxvi. 119.

The fossils of the Coralline limestone (p. 238), as Hall states, are mostly peculiar to it. Out of 32 species (including Corals, Brachiopods, Conchifers, Gasteropods, Cephalopods, and Crustaceans) only the following are set down as identical with Niagara fossils:—*Favosites Niagarensis*, *Stromatopora concentrica*,

Halysites catenulata, *Spirifer crispus*, *Atrypa lamellata*; and these are not all beyond doubt. Moreover, three of them are cosmopolite species. The beds are, therefore, strikingly different in life from the Niagara, and appear to represent a later epoch. Among the species there are very large spiral chambered shells of the new genus *Trochoceras* Hall, which are unknown in other formations.

General Observations on the Niagara Period.

Geography.—The facts upon which we have to rest our conclusions with regard to the geography of the Niagara period are,—

1st. The occurrence of the Oneida conglomerate over the region from central New York southward through the length of the Appalachians.

2d. The Medina sandstone covering the same region, but spreading a little farther westward on the north.

3d. The Clinton group having the same range on the east and extending over a considerable part of the interior basin to the Mississippi; shales characterizing the formation in the Appalachian region, shales and sandstones prevailing over limestone in New York, and limestones, more or less argillaceous, mostly constituting the beds in the West.

4th. The Niagara rocks having nearly the same eastern limit in New York (that is, absent almost entirely from the eastern third of the State); spreading over the Appalachian region and also through a large part of the interior basin; consisting of shales with some limestone in central New York, more limestone in the western part of the State, shales almost solely in the Appalachians, limestones in the West.

5th. The formations six to eight times thicker in the Appalachians than in the West.

The position of the coarse conglomerate rocks of the Oneida epoch, spreading neither over eastern New York nor the interior basin west of the State, apparently indicates that along its line was the sea-coast of the time, and that the ocean reached it in full force. Such coarse beds of marine formation are formed either in front of the waves, or under the action of strong marine currents. The latter never have sufficient force for the purpose, except in narrow straits and over limited areas, and are not capable of making accumulations of so great extent. It is stated on page 228 that the Appalachian region in Vermont, if not also in southern New England, must have been out of water: the absence of this formation and the others of the Niagara period from eastern New York harmonizes with this view.

The fine sandy and clayey character of the Medina beds shows

that at this time the same coast-region must have become an extensive area of low, sandy sea-shores, flats, and marshes, not feeling the heavy waves; and this kind of surface extended westward over Michigan, instead of having a limit in central New York. There is abundant evidence, in the ripple-marks, wave-marks, rill-marks, and sun-cracks, of shallow waters, emerging sand-flats, and low shores.

The clays, clayey sandstones, and limestones of the Clinton epoch through New York and the Appalachians show that the Medina condition of the coast-region still continued, except that the marshes were at times shallow seas where impure limestones could be formed; and the many alternations of these limestones with shales and sandstones imply frequent changes of depth over these areas, as remarked by Hall. At the same time, the westward extension of the formation, and the prevalence of limestones, indicate that the waters occupied a considerable part of the Interior Continental basin; while the impurity of the rock suggests that these inner seas were in general quite shallow. The beds of argillaceous iron-ore, which spread so widely through New York and some of the other States west, could not have been formed in an open sea; for clayey iron-deposits do not accumulate under such circumstances. They are proof of extensive marshes, and, therefore, of land near the sea-level. The few fragments of Crinoids and shells found in these beds are evidence that they were, in part at least, salt-water marshes, and that the tides sometimes reached them.

The shales of the Niagara epoch on the east indicate no great alteration of the coast-region after the Clinton epoch; but the increasing proportion of limestones to the westward, and their great thickness and comparative purity in western New York, and still greater prevalence in the States beyond, teach that the interior sea had become nearly what it was in the Trenton period. It was, however, more beautiful in its life; for Corals and Crinoids were a marked feature of the epoch.

Let us turn back now to the Trenton period, in review. There was then a shallow sea over the whole interior (with small exceptions), and it covered even the Appalachians, for here, also, limestones were formed; and any sea-coast of sands, pebbles, or muddy flats must have been farther east, where some portion of the continental border may have been raised to the surface through a slight bending upward of that part of the earth's crust. (This border now extends to a line 80 miles at sea [see p. 12 and fig. 664].) In the Hudson period there appears to have been a partial subsidence of the outer barrier and a shallowing of the interior sea by

the rising of the bottom. In the Oneida epoch, which opened the Upper Silurian, we have evidence only of an exposed coast-line in the face of the waves,—the former barrier being more sunken, and the bottom of the Interior Continental sea risen quite above the level of the waters, so as to make dry land where before was a profusion of marine life. In the Medina epoch the bold sea-coast becomes a flat coast-region, with sand-flats and marshes, and to the northward the waters spread west of New York State. In the Clinton epoch the coast-region is similar to that in the Medina, but the waters cover largely the Mississippi basin, and the interior sea once more begins to appear. In the Niagara epoch the Interior Continental basin is again a continental sea full of marine life, and through a large part of it limestone reefs are in progress.

If the above is a correct view of the geographical changes, it is seen that they consisted in a grand though small oscillation over the continent,—a rising and sinking again of the interior; and in its course the interior seas became dry land at the close of the Lower Silurian. If so, there is no need of any other explanation of the extinction of life that then happened, or of the exception to the thoroughness of the extinction in the Eastern border basin at Anticosti,—if actually an exception (p. 231).

In the course of these oscillations, from the beginning of the Trenton to the close of the Niagara period, 12,660 feet of rock were deposited along the Appalachians. From this datum the slowness of the oscillation may be estimated. The whole amount of change of level over the Interior Continental basin may not have exceeded 1000 feet.

But the Appalachian deposits show a vast amount of subsidence which was in slow progress as the accumulations went on. Without the subsidence, great breadth of deposits might have been formed, but not great thickness.

With regard to the continent beyond the Mississippi we have small basis for a conclusion. About the Black Hills and Laramie Range Dr. Hayden found the Carboniferous strata resting on those of the Potsdam period, and, therefore, an absence of all the formations of the Lower Silurian above the Potsdam, of all the Upper Silurian, and of all the Devonian. Similar facts are reported from Arkansas. About the El Paso Mountains in New Mexico, between the rivers Pecos and Grande (near lat. 32°), Dr. G. G. Shumard found a limestone of the Trenton or Hudson periods, containing the fossils *Orthis testudinaria, O. occidentalis* H., *Rhynchonella capax* Conrad, and others; but to this succeeded the Carboniferous. It would seem, therefore, that a part of the region beyond the Mississippi was in no condition for the formation of limestones or sandstones between the Lower Silurian and the Carboniferous; and the most probable supposition is that the land was not under water, although it was afterwards ex-

tensively submerged in the Coal era. Had the absence of these formations been due to deep submergence,—too deep for animal life,—the slopes of some of the mountains—as the Laramie Range or Black Hills—would have borne evidence in the presence about them of some of the beds representing the Lower Silurian and Devonian periods. The larger part of the eastern slope of the Rocky Mountains is covered by Mesozoic and later strata; and hence no certain inference can be drawn as to the extent of this dry land.

The Niagara period was a period of continental submergence also in Arctic America and Europe at this time. Even Great Britain had its Coral and Crinoidal seas, and limestone formations in progress,—although the Silurian there contains comparatively little limestone, owing to the fact that the country lies, like the Appalachian region, within the mountain-border of a continent.

Life.—Remarks with regard to the life of the period are deferred till the closing pages on the Upper Silurian, with a single exception. There is abundant evidence of extensive low flats and marshes over the continent in the Medina and Clinton epochs: the ore-beds of the latter are decisive proof on this point. The absence, therefore, of the remains of land-plants from these beds may be regarded as nearly sure demonstration that no *land-plants* then existed. Taking this into connection with the evidence from other regions, and the other formations of the period, there can be no reasonable doubt on this point.

SALINA PERIOD (6).

Epochs.—1. LECLAIRE epoch, or that of the Leclaire and Galt limestones (6 *a*); 2. SALIFEROUS epoch, or that of the Onondaga Salt group (6 *b*).

I. Rocks: kinds and distribution.

The Niagara period had covered the sea-bottom mainly with limestones. With the opening of the Salina period there was a change by which shales or marls and marly sandstones, with some impure limestones, were formed over a portion of New York; and in some way the strata were left impregnated with salt, and also almost destitute of fossils.

The beds spread through New York, and mostly south of the Erie Canal. They are 700 to 1000 feet thick in Onondaga and Cayuga cos., and only a few feet on the Hudson.

The following sections (figs. 413, 414, from Hall), taken on a north-and-south line south of Lake Ontario, show the relations of the Salina beds (6) to those above and below,—they being underlaid

in one section (fig. 414) by the Niagara (5 *d*), Clinton (5 *c*), and Medina (5 *b*) beds, and overlaid in the other (fig. 413) by rocks

Fig. 413.

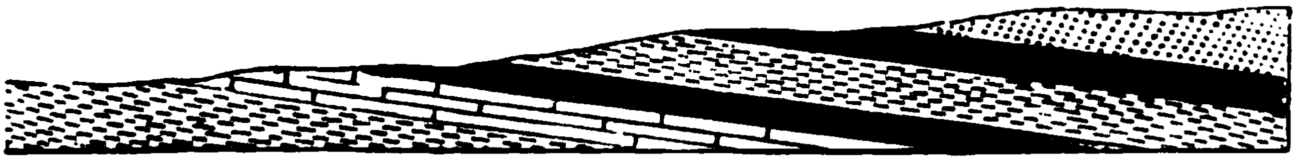


Fig. 414.

of the Upper Helderberg (7), Hamilton (8 *a*, 8 *b*, 8 *c*), and Chemung groups (9).

To the westward they outcrop between Niagara and Lake Huron, and also about Mackinac; beyond, thin beds in Wisconsin and Iowa have been referred to this period.

In western Canada the formation is underlaid by a limestone at Galt; and the same has been identified by Hall at the Rapids of Leclaire, in Iowa, where it has been called the Leclaire limestone.

In Onondaga co., N.Y., the beds in the lower half are (1) tender, clayey deposits (called marls) and fragile clayey sandstones of red, gray, greenish, yellowish, or mottled colors; and in the upper half (2), calcareous marls and an impure drab-colored limestone containing beds of gypsum, overlaid by (3) an hydraulic limestone. This limestone afforded Dr. Beck on analysis—Carbonate of lime, 44.0, carbonate of magnesia, 41.0, clay, 13.5, oxyd of iron, 1.25. The upper division is said to contain acicular cavities once filled by Epsom salt (sulphate of magnesia). The rock is sometimes divided by columnar striations like the Lockport limestone, and the structure has been attributed to the crystallization of the magnesian sulphate (Vanuxem), or else to that of salt or gypsum (Hall). The seams sometimes contain a trace of coal or carbon.

Near Syracuse there is a bed of serpentine in this formation, along with whitish and black mica and a granite-like rock. (Vanuxem.) In part of it hornblende replaces the mica, making a syenite. There is little evidence of heat in the beds adjoining these metamorphic rocks.

In the peninsula of Michigan the formation includes—beginning below—10 feet of variegated gypseous marls, 14 feet of ash-colored argillaceous limestone, 3 feet of calcareous clay, and 10 feet of chocolate-colored limestone. (Winchell.)

The rocks of this period have not been distinguished from those of the Niagara period in the Appalachian region in Pennsylvania or to the southwest in Virginia.

The beds, especially those of the upper half, are much inter-

sected by shrinkage-cracks,—effects of the drying of the mud of the ancient mud-flat by the sun.

Minerals.—The gypsum does not constitute layers in the strata, but lies in imbedded masses, as shown in the annexed figures.

Fig. 415.

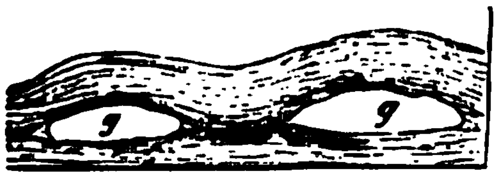
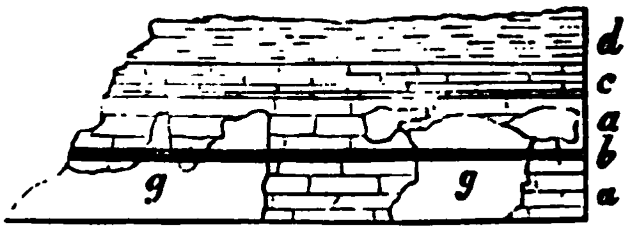


Fig. 416.



The lines of stratification sometimes run through it, as in fig. 416; and in other cases the layers of the shale are bulged up around the nodular masses (fig. 415). Both cases show that the gypsum was formed after the beds were deposited. Sulphur springs are now common in New York, and especially about Salina and Syracuse. Dr. Beck describes several occurring in this region, and mentions one near Manlius which is "a natural sulphur-bath, a mile and a half long, half a mile wide, and 168 feet deep,—a fact exhibiting in a most striking manner the extent and power of the agency concerned in the evolution of the gas," and showing, it may be added, that the effects on the rocks below must be on as grand a scale. These sulphur-springs often produce sulphuric acid by an oxydation of the sulphuretted hydrogen. There is a noted "acid spring" in Byron, Genesee co., N.Y., connected with the Onondaga formation, besides others in the town of Alabama. This sulphuric acid acting on limestone (*carbonate* of lime) drives off its carbonic acid and makes *sulphate* of lime, or gypsum; and this is the true theory of its formation in New York. The laminæ which pass through the gypsum unaltered, as in fig. 416, are those which consist of clay instead of limestone. The gypsum is usually an earthy variety of dull gray, reddish and brownish, sometimes black, colors. It may have been produced at any time since the deposition of the rocks; and it is beyond doubt now in progress at some places in the State.

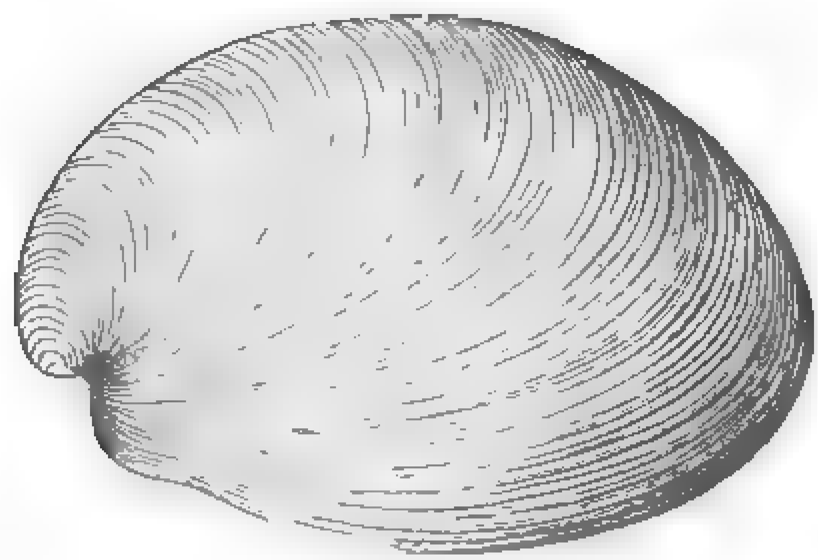
The salt of the rocks is found only in solution in waters issuing from the strata. At the present salt-works of Salina and Syracuse the brine is obtained by borings. The wells are 150 to 310 feet deep at the former place, and between 255 and 340 at the latter. 35 to 45 gallons of the water afford a bushel of salt; while it takes 350 gallons of sea-water for the same result.

II. Life.

The Salina beds are for the most part destitute of fossils. The lower beds in New York contain a few species imperfectly preserved; and the same is true of the upper. The latter, however, are regarded as rather of the next (Upper Helderberg) period.

In the limestone at Galt there are a number of shells, and two of them—*Murchisonia Boydii* and *Cyclonema sulcata*—are set down by Hall as identical with species in the lower part of the Onondaga Salt group. The fossils of this and

Fig. 416 A.



Megalomus Canadensis.

the Leclaire limestones have been shown by Hall to be very different from those of the Niagara beds.

Fig. 416 A represents one of the Conchifers, the *Megalomus Canadensis*, a species that is occasionally found four inches long. Besides this there are a Pentamerus, *P. occidentalis*, a species of *Murchisonia*, an *Orthoceras*, and a *Calymene*.

General Observations.

Geography.—The position of the Saliferous beds over the State of New York indicates that the region which in the preceding period was covered with the sea and alive with Corals, Crinoids, Mollusks, and Trilobites, making the Niagara limestone, had now become an interior shallow basin, or a series of basins, mostly shut off from the ocean, where the salt waters of the sea, which were spread over the area at intervals,—intervals of days or months, it may be,—evaporated and deposited their salt over the clayey bottoms. In such inland basins the earthy accumulations in progress

would not consist of sand or pebbles, as on an open sea-coast, but of clay or mud, such as is produced through the gentle movements of confined waters. Moreover, the salt waters would become under the sun's heat too densely briny for marine life, and at times too fresh from the rains; and the muddy flat might be often exposed to the drying sun, and so become cracked by shrinkage. The shrinkage-cracks, the clayey nature of the beds, the absence of fossils, and the presence of salt, all accord with this view. Salt cannot be deposited by the waters in an open bay, for evaporation is necessary. The warm climate of the Silurian age and the absence of great rivers were two conditions favorable for such results. At one small coral island in the Pacific, visited by the author, the lagoon (or lake) which formed the interior was shut off from free communication with the ocean, and consequently some of the above-mentioned conditions were well exemplified. The waters became extremely salt in the hot season, and fresh in the rainy months; and hence no living corals or shells existed there, although once abundant. Moreover, while the rock was of coral origin, there were no fragments of corals or shells along the shores of this lagoon, but, instead, a deep mud of calcareous material, made out of the broken shells and corals by the triturating wavelets,—so deep and adhesive that the waters of the lagoon were somewhat difficult of access. This calcareous mud, if solidified, would become a non-fossiliferous limestone, like a large part of the coral rock; and yet a few hundred yards off on the sea-coast there were other limestones forming, that were full of corals and shells.

The Saliferous flats of New York spread across the State, and probably opened on the ocean to the southeast. The existence of such interior evaporating flats implies intermittent incursions of the sea, perhaps only through tidal overflows, but probably such occasional floodings as may take place where there are coast-barriers or reefs that are broken through at times by the waves or currents.

The existence of such barriers is no unreasonable assumption; for the coast of the United States is now to a great extent bordered with them. They stretch along the south side of Long Island, shutting in a narrow area of salt water; and south of New York they occur off New Jersey, Maryland, Virginia, and the Carolinas, making the various sounds that are so characteristic of the coast-region.

As the Saliferous beds of New York are nearly 1000 feet thick just west of the centre of the State, and since there is proof in the

shrinkage-cracks and other peculiarities that the layers were successively formed in shallow waters, it follows that there must have been a slow subsidence of the region during the progress of the period,—it may have been but a few inches or feet in a century. In water ten feet deep, a bed ten feet thick, or a little over ten, may form; but with a slow sinking, at a rate not beyond the rapidity of deposition, the beds may reach any thickness, limited only by the cessation of the subsidence.

Life.—The half-submerged marshes or flats of this period, bordered by dry land at least on the north, and probably including dry areas over their surface, would have given an opportunity for forest-trees to grow and forest-animals to live where their remains would be sure to find a safe burial, as they did in after-times. Yet, as in the Medina and Clinton epochs, no trace of a leaf, or stem, or relic of a land or fresh-water animal has been afforded by the beds.

The extermination of life at the close of the Niagara period was very nearly complete in the region of New York, while apparently only partial in the interior basin, as in Tennessee. The cause of the extinction was connected, no doubt, with the changes that ushered in the Salina period; and the existence of seas over portions of the interior accounts both for the limestones of the Salina epoch and the continuation of a portion of the Niagara life beyond the termination of the period. The beds of the Mississippi basin require a fuller elucidation for safe inferences.

LOWER HELDERBERG PERIOD (7).

I. Rocks: kinds and distribution.

The Lower Helderberg period was one of abundant marine life, and of the formation of thick limestone strata,—a period, therefore, not of prevailing salt marshes, but of clear seas over the submerged land.

The formation in New York has its greatest thickness at the Helderberg Mountains south of Albany, where it is over 200 feet; and hence the name of the period.

The beds extend westward in New York, and gradually thin out in Ontario county, being wholly absent from the western part of the State. The beds have been reported to occur in Ohio, Missouri, and Tennessee; but according to the more recent investigations they are wanting over the interior basin.

Near Montreal, in Canada, a small patch overlies unconformably the Hudson River shales.

South of New York, along the Appalachian region they extend through New Jersey, Pennsylvania, Maryland, and Virginia, increasing in thickness, being in all 500 feet or more on the Potomac; and, as in the North, they diminish westward.

The subdivisions of the formation observed in the Helderberg Mountains are for the most part undistinguishable out of New York State. The lowest rock, the *Water-lime*, retains its characters most widely, and has a thickness on the Potomac of 350 feet (Rogers). Moreover, in New York it extends west to Ontario co., which is beyond the beds higher in the series. The water-lime is so called because used for making water- (or hydraulic) cement. It is a drab-colored or bluish impure limestone, in thin layers.

The several New York subdivisions are as follow:—

5. Upper Pentamerus limestone.
4. Encrinal limestone.
3. Catskill or Delthyris shaly limestone.
2. Pentamerus limestone, 50 feet in the Helderberg Mountains.
1. Tentaculite and Water-lime group, 150 feet in the Helderberg Mountains.

An analysis of the Water-lime rock afforded Dr. Beck—Carbonate of lime, 48.4, carbonate of magnesia, 34.3, silica and alumina, 13.85, sesquioxyd of iron, 1.75, moisture and loss, 1.70. One of the beds of the Water-lime strata, consisting of thin clinking layers, abounds in fossils called *Tentaculites*, and has been named *Tentaculite limestone.*

The *Pentamerus limestone* (No. 2), overlying the Water-lime, is so called from its characteristic fossil, *Pentamerus galeatus* (fig. 422). It is compact, and mostly in thick layers. The *Catskill* or *Delthyris shaly limestone* (No. 3) consists of shale and impure thin-bedded limestone, and in many places in New York abounds in the large fossil shell *Spirifer macropleurus*, and extends as far west as Madison co. It is full of fossils. The *Encrinal limestone* (No. 4) is confined to the eastern part of the State. The *Upper Pentamerus* (No. 5), the upper layer, is of limited extent, but has many peculiar fossils: it is named from the *Pentamerus pseudo-galeatus* (figs. 424, 425).

The Saliferous beds pass rather gradually into the Water-lime,—their upper layers becoming more and more calcareous, and containing some of the Water-lime fossils. The range of the Salina and Lower Helderberg formations is very different; for the former is thickest west of the centre of New York, and the latter on its eastern border.

In the *Appalachian region* in Pennsylvania the Water-lime group has in the middle belt of the mountains a thickness in some places of 350 feet, while in the southeast belt it is 50 to 200 feet; it thickens to the southwestward. The rest of the Lower Helderberg, consisting also of impure limestones, has a thickness of 100 feet or more in the middle belt, and 200 to 250 in the south-eastern, which thickness is maintained along the Appalachian chain. (Rogers.)

In the *Eastern border region*, at Pembroke, Me., in a granitic region, slates and hard sandstones occur with many fossils; at other places in northern Maine, the rock is limestone. In Cutler and Lubec, Me., there is a fossiliferous limestone, either of this or the Niagara period. (C. H. Hitchcock.)

II. Life.

This period was prolific in species, beyond even the Niagara or Trenton; over 300 have been named and described. Among them there are the same families and genera as in the preceding periods, but with some marks of progress in new forms, and with a range of species almost completely distinct. Yet it has been noted as a striking fact that very many of the species of the Niagara period have their closely-related or representative species in the Lower Helderberg.

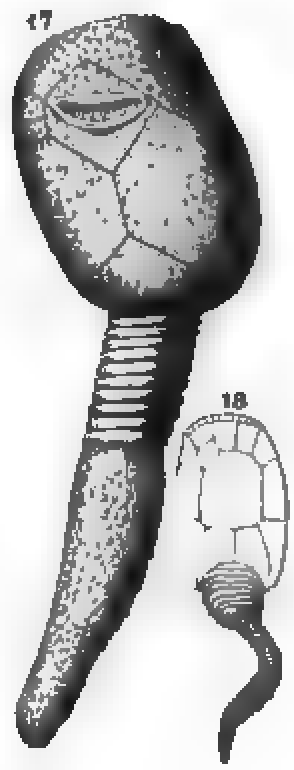
1. *Plants.*

Limestone strata seldom contain remains of plants; and, accordingly, little is known of the botany of the Lower Helderberg period.

2. *Animals.*

Many Corals and Crinoids occur in the beds, and some of the latter are of remarkable size and beauty,—as the *Mariacrinus nobilissimus*, and other species of the same genus. The last of the *Halysites*, or Chain-coral, existed in this period, and a few species of *Cystids* (figs. 417, 418). *Brachiopods* still take the lead in numbers of all other kinds of life. In the Water-lime one layer is full of the little *Tentaculites ornatus* (figs. 431, 432). Among the Trilobites the *Dalmania pleuroptyx* (fig. 244 C) is a common form. Quite a different form of Crustacean appears for the first time in these rocks. It is represented in the *Eurypterus remipes* Dekay (fig. 433). Unlike Trilobites, it has large jointed arms, and a body which resembles that of the Sapphirina and Caligus groups of modern Crustaceans. (Figs. 175, 176 represent the female and male of a Sapphirina from our own seas. See page 151.)

Figs. 417, 418.



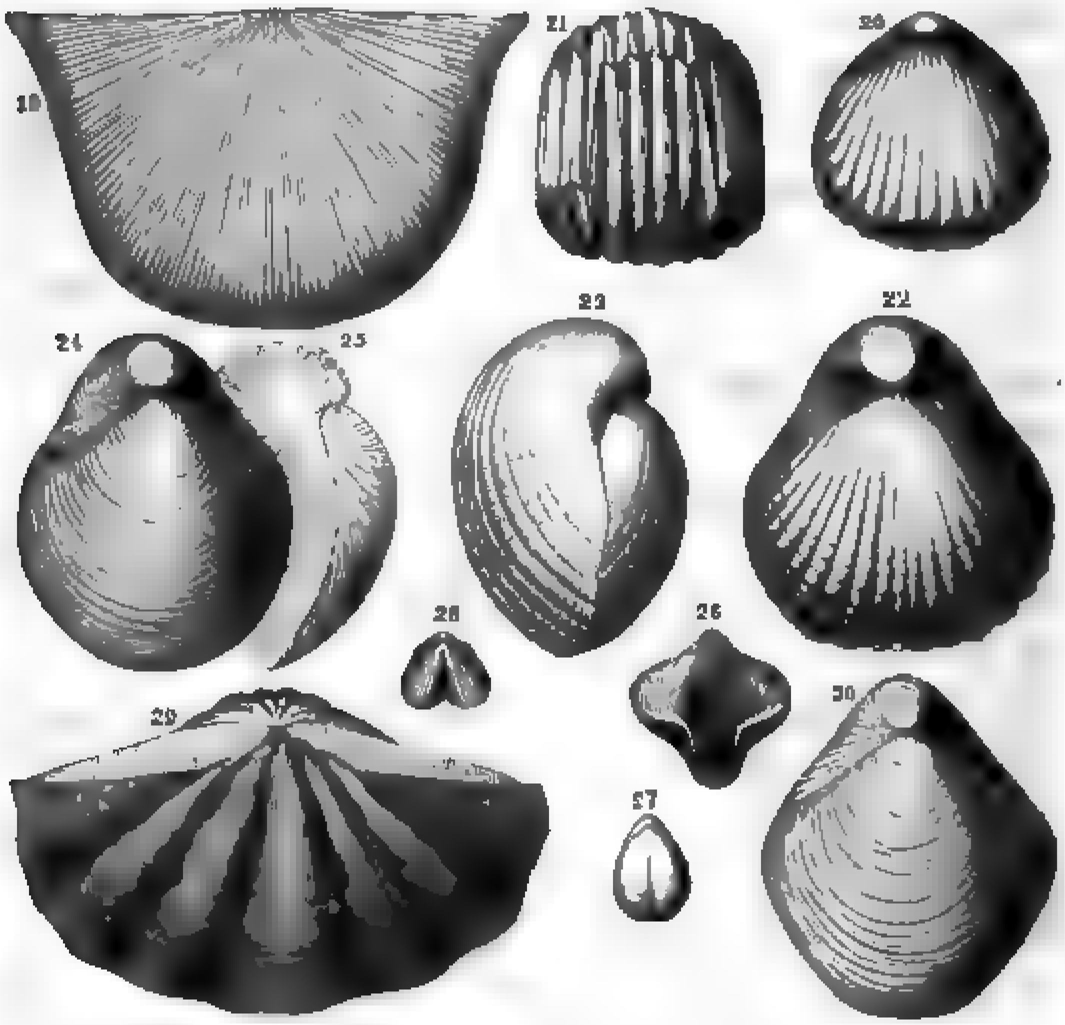
CYSTIDEANS.—Fig. 417, Apiocystis; 418, Anomalocystis.

Characteristic Species.

1. **Radiates.**—(*a.*) *Polyps.*—Among Corals there are species of *Zaphrentis*, *Favosites*, *Stromatopora*, *Halysites*, *Syringopora*, *Chætetes*. (*b.*) *Echinoderms.*—Group of Cystideans: Fig. 417, *Apiocystis Gebhardi*, found in the Lower Pentamerus; fig. 418, *Anomalocystis*, a remarkable species from the same rock. In the group of Crinideans there are species of the genera *Mariacrinus*, *Platycrinus*, *Edriocrinus*, *Aspidocrinus*, etc.

2. Mollusks.—*Brachiopods.*—Fig. 419, *Strophomena radiata* Vanuxem, of the Catskill shaly limestone; 420, 421, *Rhynchonella ventricosa*, of the

Figs. 419–430.



BRACHIOPODS.—Fig. 419, Strophomena radiata; 420, 421, Rhynchonella ventricosa; 422, 423, Pentamerus galeatus; 424, 425, P. pseudo-galeatus; 426, Eatonia singularis; 427, Merista? sulcata; 428, Orthis varica, 429, Spirifer macropleurus; 430, Merista levis.

Upper Pentamerus; 422, 423, *Pentamerus galeatus*, of the Lower Pentamerus; 424, 425, *P. pseudo-galeatus*, of the Upper Pentamerus; 426, *Eatonia singularis*, of the Catskill shaly; 427, *Merista? sulcata*, of the Water-lime; 428, *Orthis varica*, of the Catskill shaly; 429, *Spirifer macropleurus*, ibid.; 430, *Merista levis*, ibid.

There are also Conchifers of the genus *Avicula* and others related; Gasteropods of the genera *Platyceras*, *Platyostoma*, etc. Also the Pteropod *Tentaculites ornatus* (figs. 431, 432, the latter natural size).

3. Articulates.—(*a.*) *Trilobites.*—Fig. 244 C, *Dalmania pleuroptyx*; others of the genera *Calymene*, *Cheirurus*, *Asaphus*. (*b.*) Other *Entomostracans.*—Fig. 433, *Eurypterus remipes*, of the Water-lime, natural size, from a small specimen from the cabinet of E. Jewett: specimens from Buffalo, N.Y., are some-

times six inches or more in length. Species also occur in this rock belonging to the allied genus *Pterygotus* (fig. 440 is a foreign species), and to the Phyllopod genus *Ceratiocaris*, both of which genera were first described in England. The latter has some resemblance to fig. 262 A. Fig. 434, *Leperditia alta*, an Ostracoid, abundant in the Water-lime.

Figs. 431–434.

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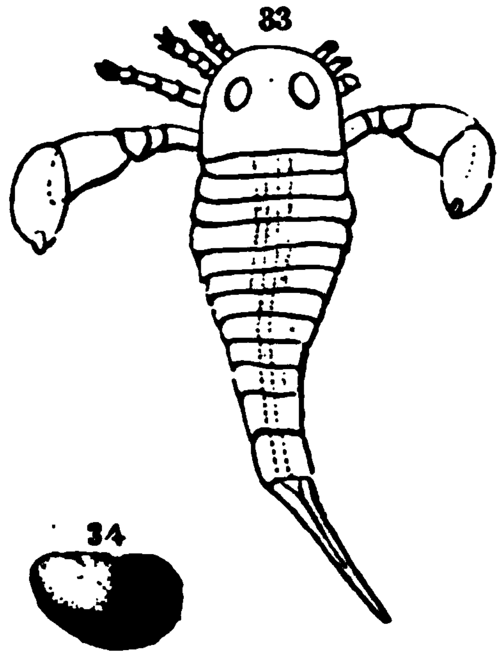

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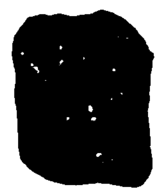


Tentaculites ornatus.

CRUSTACEANS.— Fig. 433, Eurypterus remipes, a small specimen; 434, Leperditia alta, natural size.

The following is a list of the characteristic species of the subdivisions :—

1. Water-lime.—*Merista sulcata, Avicula rugosa, Leperditia alta, Tentaculites ornatus.*

2. Lower Pentamerus.—*Apiocystis Gebhardi, Rhynchonella semiplicata, Pentamerus galeatus, Euomphalus? profundus.*

3. Catskill Shaly Limestone.—*Strophomena radiata, S. punctulifera, Merista levis, Eatonia singularis, Spirifer macropleurus, Sp. perlamellosus* (formerly *rugosus*), *Platyceras ventricosum, Dalmania pleuroptyx* H. (formerly D. Hausmanni).

4. Upper Pentamerus.—*Pentamerus pseudo-galeatus, Rhynchonella ventricosa, R. nobilis, Spirifer concinnus.*

Atrypa reticularis and *Strophomena rugosa* are among the few species of the Niagara period which occur in the rocks of the Lower Helderberg.

In Perry co., Tennessee, there is apparently a mingling of the fossils of the Niagara and Lower Helderberg periods in a single thin layer, and it has not yet been found easy to separate them into the two periods.

It is quite possible that in the interior of the Mississippi basin many of the Niagara species were continued into the Lower Helderberg period.

III. General Observations.

Geography.—In the Salina period, as already explained, the limestone-making seas of the Niagara period in New York had been succeeded by a great range of muddy flats and shallow basins; and in the West the basin had apparently become much contracted in area, judging from the limited extent of Salina limestones. Neither of these formations reaches to eastern New York.

In the Lower Helderberg period, which succeeds, there was a return of the conditions for making limestones; but, in striking contrast with the formations that preceded, the beds have their greatest thickness in *eastern* New York, and none occur in western.

Here, then, a new phase in American geography is brought out to view. The Lower Helderberg limestones are mainly Appalachian formations; for even the New York part is directly in the range of the Appalachians of Pennsylvania. It is worthy of note that this limestone formation of the last period of the Upper Silurian is the first one that was produced over the Appalachian region after the Trenton in the middle of the Lower Silurian. But the Trenton beds spread over both East and West, while the Lower Helderberg occur only sparingly in the West; and in this the two periods are in contrast, the older formation having the widest distribution.

The sinking of eastern New York which was required for the formation of the Lower Helderberg limestones probably submerged, wholly or in part, the Green Mountain region, which appears to have been dry land in the Niagara period. That it affected the rest of the Appalachian region to the southwest is manifest from the distribution of the rocks in that direction. Outside of the limestone-making seas in face of the Atlantic waves there were probably barriers of sand thrown up by the sea, or of emerged land, repeating in this respect the condition in the Trenton period. It is true that limestone reefs may and do form on an exposed coast; but only in case the submerged bottom of the continental border (which at this time was over 100 miles wide) was not so near the surface that its sands or mud could be thrown over the growing reefs by the waves or currents. Limestones have been made for the most part from the relics of species that require clear water, like the coral limestones of existing seas. So great a breadth of shallow border as that of the American coast could hardly have existed at the time without sand-reefs being thrown up to fend off the waves, unless the whole were deeply submerged.

OBSERVATIONS ON THE AMERICAN UPPER SILURIAN.

General features.—Fresh-water lakes and rivers, fresh-water deposits, and land or fresh-water animal life, continue unknown through the American records of the Upper Silurian, as thus far investigated. Such rivers and lakes probably existed, as it is certain there was dry land; but they have left nothing that survived subsequent changes. It is barely possible that some of the Mollusks may have lived in fresh waters; but the remains are so mingled with species that are obviously salt-water types that it cannot be proved to be true of any.

With regard to land-plants there is some doubt. Certain sub-

cylindrical fossils found in the island of Anticosti (p. 231) have been referred to plants and named *Beatricea*. Similar fossils occur also in Kentucky. But the ambiguous character of the fossils, their occurrence in limestone, and the non-occurrence of any land-plants in the marls—originally marshes—of the Salina period, make their vegetable nature very doubtful. It is not impossible that leaves and stems of true land-plants may yet be found; but it is very remarkable that, if existing, the beds of shale and argillaceous sandstone should have been so extensively explored without finding them.

Conditions of the Continent.—The survey of the successive formations of the Upper Silurian teaches that the geological changes in progress were, like those of the earlier Silurian, of continental extent. The causes in action were not making a mere edging to the continent, as in Tertiary times, but were building up the very continent itself by wide-spread accumulations of limestone, sands, and clays.

Moreover, the continental seas were not the ocean's bed. In many of the epochs, the ripple-marks and cracks from sun-drying prove the shallowness of the water over great regions and a wide expanse of exposed beaches and marshes in others. The corals and the profusion of marine life in the limestones are also proofs of shallow waters. No greater depth than 500 feet is indicated by any of the species; and as corals were probably limited then, as now, to within twenty fathoms of the surface,—for they can make solid limestones only where the waves can help them,—the continental seas must have been to a considerable extent much less deep.

The continental areas still included little permanent dry land. The continent had enlarged somewhat since the Azoic age; but the greater part of the United States was yet to be completed by the deposition of the Devonian, Carboniferous, and later beds.

Contrast between the Interior and the Appalachian regions.—The shales and sandstones which prevail in the East from the vicinity of the Azoic of New York southwest along the Appalachian region are mostly wanting in the West, where the Niagara limestone is widely distributed. In some places on the north there is a limestone of the Salina period. The West was therefore in certain parts still making limestones while the East interposed between its limestones extensive clay and sand deposits. The limestones of the West prove slight changes of level there; the argillaceous beds and sandstones of the East, great oscillations over the Appalachian region; and in the Niagara period they

amounted in Pennsylvania to at least 500 feet in the Oneida epoch, 1500 feet in the Medina, over 2000 feet in the Clinton, 1500 feet in the Niagara and Salina, and 500 in the Lower Helderberg,—in all 6000 feet. In the Salina period, the subsiding area stretched up into New York west of its centre; for it was there that the Salina beds were formed to a thickness of 1000 feet.

Life.—(*a.*) *General features.*—The range of animal life was in its grander divisions the same as in the later part of the Lower Silurian. The highest species continued to be the Cephalopods,—the first among Mollusks, and that group among Invertebrates that more than any other embraced characters of the Vertebrates; for example, perfect organs of sight, hearing, and touch, great size and strength, and powerful arms for prehension. The Crustaceans belong to a higher type,—the Articulate,—but only to the lower division of that type. The Vertebrates are yet unknown among American Silurian fossils.

While the grand types remained the same, there were changes through the disappearance of many genera and families and the introduction of others.

(*b.*) *Radiates.*—The group of Graptolites, which passed its climax in the Lower Silurian, had its last species in the Clinton epoch of the Upper Silurian. Crinideans were brought out in many new genera and an increasing number of species. Corals became much more varied; the Chain-corals (*Halysites*) were common, but passed away with the Upper Silurian; the Favosites and the Cyathophylloids also increase in abundance, and abound still later in the Devonian.

(*c.*) *Mollusks.*—Mollusks—the dominant type of the seas—are most abundantly represented by Brachiopods. Among them, the genera *Spirifer*, *Athyris*, *Chonetes*, and others, were added to *Lingula*, *Orthis*, *Leptæna*, *Rhynchonella*, *Atrypa*, etc. of the Lower Silurian; at the same time, *Orthis* had lost its pre-eminence, and was of few species. The Lower Silurian Brachiopods have no bony arm-supports internally, excepting the very short ones in *Rhynchonella*. In both *Spirifer* and *Atrypa* these supports were long and rolled spirally. The genus *Spirifer* commences with narrow species, little broader than high, but in the later part of the Upper Silurian they are already much wider (fig. 429), though not as extravagantly so as in many of the species in the Devonian and Carboniferous ages.

The Conchifers and Gasteropods are few compared with the Brachiopods; and in both groups the species are mostly siphonless; that is, the Gasteropods have the aperture without a beak,

and the Conchifers, with the exception of the Cardium family, have the pallial impression entire (fig. 163). The species of Conchifers are mostly of the *Mytilus*, *Avicula*, *Arca*, and *Cardium* families; those of the Gasteropods, mainly of the *Bellerophon* and *Trochus* families. The *Tentaculites* have their climax in the Upper Silurian, occurring in great numbers in some of the rocks; after this they are comparatively rare. Among Cephalopods, the *Orthocerata*, while common, are not so large nor so numerous as in the Lower Silurian.

The genus *Ormoceras*—with large beaded siphuncle—ceases with the Niagara period. Both the straight and the curved or coiled shells have the partitions simply arched, and not plicate as in after-time. The *Conulariæ* are more numerous and larger than before.

(*d.*) *Articulates.*—The sub-kingdom of Articulates still embraces only the water-types of Worms and Crustaceans. Trilobites are multiplied in genera,—*Homalonotus* and *Phacops* being added to *Calymene*, *Agnostus*, *Asaphus*, *Illænus*, *Lichas*, *Acidaspis*, and *Dalmania* of the Lower Silurian. The bivalve Crustaceans, or Ostracoids, are very common. In the *Eurypterus* (fig. 433) there is a new step in the development of the Crustacean type, yet one still within the lowest order, that of Entomostracans. It was observed, p. 203, that Trilobites and Phyllopods were *comprehensive* types,—that is, types embracing features of other unexpressed groups of Crustaceans, and not typical Entomostracans. The Ostracoids, also, are a peculiar group, and have a close resemblance in general structure to the young of a tribe that appears long afterwards,—the one including the Cirripeds (Barnacles and Anatifas, p. 154). With the *Eurypterus* commences the typical Entomostracan. It belongs to the same general group with the *Cyclops* and *Sapphirina*,—the *Cyclopoids*,—the largest tribe in the order of Entomostracans.

(*e.*) *Extinction of species.*—The number of Upper Silurian species thus far described from the American rocks is about 680, which is at least 200 short of the number existing in collections. Not a species existed in the later half of the Upper Silurian that was alive in the later half of the Lower Silurian. Less than a dozen species are continued into the Devonian, and these disappear long before the close of that age.

(*f.*) *Genera of existing seas.*—To the list of existing genera no additions are made in the course of the Upper Silurian. All but the few before enumerated, *Lingula*, *Discina*, *Nautilus*, *Rhynchonella*, and *Crania*, become extinct.

Climate.—There is no evidence that the climate of America included frigid winds or seas. The living species in the waters

between the parallels of 30° and 45° were in part the same, or closely related in species, with those that flourished between the parallels of 65° and 80°. (See pages 238 and 242.) From this life-thermometer we learn only of warm or temperate seas.

FOREIGN UPPER SILURIAN.

The rocks of the Upper Silurian are as widely distributed over the globe as those of the Lower Silurian, occurring in Great Britain, Spain, France, Germany, Russia, Sardinia, and other countries of Europe, and in Asia, Africa, and Australia. Throughout, they sustain the principle that these early formations are in general of continental range. They seem on a geological map to cover but small areas, but only because they are concealed by later formations: they lie underneath.

The table on page 168 exhibits some of the foreign equivalents of the American Upper Silurian.

The equivalents of the Niagara period in Great Britain are (1) the Lower Llandovery beds of South Wales (especially near Llandovery), supposed to correspond to the Medina group; (2) the Upper Llandovery of Shropshire and other localities (including the May Hill sandstone), corresponding to the Clinton group; (3) the Wenlock group (divided into the Lower Wenlock or Woolhope limestone, the Wenlock shale, and the Upper Wenlock or Dudley limestone), corresponding to the Niagara limestone. The Ludlow group (4) (consisting of the Lower Ludlow rocks, the Aymestry limestone and the Upper Ludlow) is regarded as corresponding to the Lower Helderberg.

The largest Upper Silurian area in Great Britain is situated near the borders of Wales and England, where are the May Hill sandstones, the Wenlock or Dudley limestone and shales, and the Ludlow argillaceous sandstones and shales, in which lies the Aymestry limestone. Another area is in northern England, on the west side, where are the Coniston limestones and grits, the Ireleth slates equivalent of the Wenlock, and the Kendal tilestones equivalents of the Upper Ludlow. There are other areas in southern Scotland and Ireland. The thickness of the British Upper Silurian is about 5000 feet.*

In Scandinavia, the limestones and sandstones of Gothland represent the Niagara, and the Calciferous flags and Upper Malmö group the Upper Helderberg. In Bohemia, the Medina and Clinton epochs are represented mainly by sandstones or quartzites, and the later Upper Silurian by limestones and schists of Barrande's formations E, F, G, H.

* The student desiring information on the Silurian of England will find the subject displayed with great fulness in Murchison's Siluria, the second edition of which appeared in England in 1859. The work also gives the best digest that has been made of the facts relating to the Silurian and other Palæozoic formations of Europe.

The following tables show the distribution in other countries of some species of the Niagara and Lower Helderberg periods.

1. *American Niagara Species occurring elsewhere.*

Halysites catenulata, Great Britain (Llandeilo, Dudley, Aymestry), Norway, Sweden, Russia, Eifel.

Heliolites pyriformis, Great Britain (Wenlock, Aymestry), France, Sweden, Russia, Eifel.

Stromatopora concentrica, Great Britain (Dudley), Sweden, Russia, Eifel.

Limaria fruticosa, Great Britain (Dudley, Aymestry), Russia.

Limaria clathrata (?), Great Britain (Dudley), Russia.

Ichthyocrinus levis (?), Great Britain (Dudley).

Eucalyptocrinus decorus, Great Britain (Dudley).

Orthis elegantula, Great Britain (Wenlock), Gothland (in Sweden).

Orthis hybrida, Great Britain.

Orthis biloba, Great Britain (Dudley), Gothland.

Orthis Flabellulum, Great Britain (Bala).

Leptæna transversalis, Great Britain, Gothland.

Strophomena rugosa (formerly *Leptæna depressa*), Great Britain (Dudley, Aymestry), Sweden, Russia, Belgium, Eifel, France, Spain.

Spirifer crispus, Great Britain (Llandeilo, Dudley), Gothland.

Spirifer radiatus, Great Britain (Dudley).

Spirifer sulcatus (?), Great Britain (Dudley).

Atrypa reticularis, Great Britain (Wenlock), Gothland, Germany, Russia (Urals, Altai).

Merista (*Rhynchonella*) *nitida*, Great Britain, Gothland.

Rhynchonella bidentata, Great Britain (Wenlock).

Rhynchonella cuneata, Great Britain (Wenlock), Gothland.

Rhynchonella plicatella, Great Britain (Wenlock, Aymestry).

Rhynchospira ? (*Atrypa*) *aprinis*, Russia.

Pentamerus brevirostris, Great Britain.

Pentamerus interplicatus; Great Britain.

Orthoceras implicatum, Great Britain (Ludlow), Gothland.

Orthoceras virgatum, Great Britain.

Orthoceras undulatum, Great Britain, Eifel.

Illænus (*Bumastis*) *Barriensis*, Great Britain (Dudley).

Phacops limulurus (?), Great Britain (Dudley), Bohemia, Sweden.

Ceraurus insignis, Bohemia.

Calymene Blumenbachii, Great Britain (Bala, Wenlock), Sweden, Norway, Bohemia, France.

Homalonotus delphinocephalus, Great Britain (Dudley).

Proëtus Stokesii, Great Britain (Dudley).

2. *American Lower Helderberg Species occurring elsewhere.*

Strophomena rugosa, Great Britain (Dudley, Aymestry), Gothland, Russia, Eifel, France, Spain.

Atrypa reticularis, Great Britain (Wenlock), Sweden, Russia (Urals, Altai), Bohemia.
Dalmania nasuta, Great Britain, Sweden, Russia.
Eurypterus remipes, Russia (island of Oesel, according to Keyserling).
Pentamerus galeatus, Great Britain (Aymestry, Dudley, Ludlow), Eifel.

There are a number of other species closely like European, but they are regarded by Hall as distinct.

3. *Arctic American Upper Silurian Species occurring elsewhere.*

Halysites catenulata, Great Britain, Norway, Sweden, Russia, U.S.
Favosites Gothlandica, Great Britain, Sweden, U.S.
Favosites polymorpha, Great Britain, France, Belgium, Eifel.
Stromatopora concentrica, Great Britain, Eifel.
Receptaculites Neptuni De France, Great Britain, Belgium, Eifel, U.S.
Orthis elegantula, Great Britain, Gothland, Russia, U.S.
Atrypa reticularis, Great Britain, Gothland, Urals, Altai in Siberia, U.S.
Pentamerus Conchidium Dalman, Gothland.
Rhynchonella sublepida ? De Verneuil, Urals.
Encrinurus levis ? Angelin, Gothland.
Leperditia Baltica Hisinger, Gothland.

There are a considerable number of species in the British Lower Silurian which pass into the Upper Silurian. They are found mingled in the intermediate Llandovery formations, which, although classed with the Upper Silurian, contain between 40 and 50 species that occur also below.

Barrande has found nearly 2000 species of fossils in the Bohemian Silurian basin above the Primordial strata. The limestone E abounds in organic remains, and among them are 400 species of Cephalopods, and 78 species of Trilobites (of the genera *Calymene, Acidaspis, Cheirurus, Cyphaspis, Lichas, Phacops, Harpes, Bronteus*, and *Proëtus*). Barrande regards this as the culminating period for the Trilobite race. Limestone F also contains 75 species of Trilobites, and of the same genera, associated with a profusion of Brachiopods. In G there are many Goniatites and other species, which show that, while the strata are intimately connected with E and F physically and in their fossils, the period probably corresponds in part with the early Devonian. Besides 40 species of Trilobites of the above genera, there are others of the Devonian genus *Dalmania*. In Bohemia 57 Lower Silurian species pass into the Upper Silurian.

A list of the genera common to the American and European continents would show almost a complete identity, and the same system of progress from the Lower Silurian onward. In each, the genera *Spirifer* and *Chonetes*, among the Brachiopods, were added to *Orthis, Leptæna*, and *Atrypa; Halysites* (Chain-corals), *Favosites*, and *Cyathophyllidæ* became abundant; Crinoids were greatly multiplied; and the *Eurypterus* group or Cyclopoid Crustaceans commenced a

new line among the Articulates; while Graptolites, so common in the Lower Silurian, were few in species and numbers, and finally became extinct before the close of the era.

There was thus a uniformity of life in the New and Old World. Similar genera made their appearance, and others their exit. In neither have we any evidence that the progress had reached to the introduction of land or fresh-water species of animals; and no relic of a land-plant has yet been discovered in the Silurian strata of Europe or Britain, except in the uppermost beds (page 264).

The following figures illustrate some of the British Upper Silurian species not yet found in America.

Figs. 435–440.

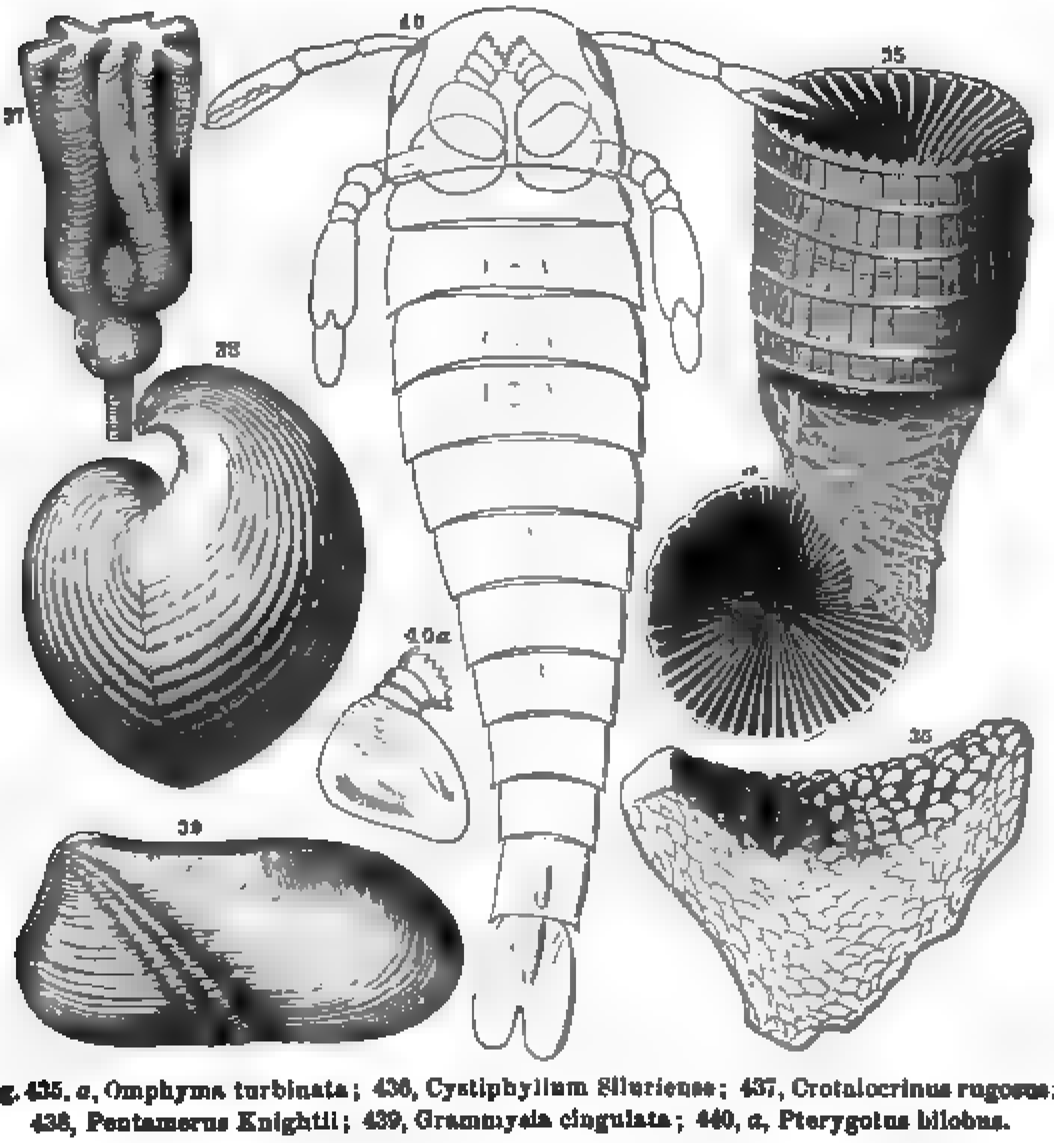


Fig. 435, a, Omphyma turbinata; 436, Cystiphyllum Siluriense; 437, Crotalocrinus rugosus; 438, Pentamerus Knightii; 439, Grammysia cingulata; 440, a, Pterygotus bilobus.

Fig. 436 is the Cyathophylloid coral *Cystiphyllum Siluriense*; fig. 435, another, *Omphyma turbinata*, reduced one-half in size; fig. 437, *Crotalocrinus rugosus*,—

all three of the Wenlock; 438, the *Pentamerus Knightii* of the Aymestry limestone; 439, *Grammysia cingulata* of Dudley; 440, the *Pterygotus bilobus*, related to the Eurypterus,—a genus some of whose species, according to Salter, were seven or eight feet long, exceeding modern Crustaceans by several feet. It is an early lesson taught by science, that size, however important in some parts of the system of nature, is no necessary criterion of rank.

On some shells traces of the original colors still remain, proving that there was beauty of coloring in Silurian times as well as now, and also that the species lived in comparatively shallow waters. Professor Forbes has stated that colors arranged in figures are not found on shells which live below a depth of fifty fathoms.

Notwithstanding the striking coincidences in species and still more in genera between the New and Old World, there are discrepancies which make it quite difficult to determine with precision the equivalency of the rocks. The Wenlock beds contain some 40 Niagara species; and still there are quite a number (among them *Dalmania Hausmanni* and *Pentamerus galeatus*) that are closely related to species found in the period of the Lower Helderberg. The Ludlow beds are related similarly to the Lower Helderberg, and still some species occur in them that in America exist only in the Devonian. This is so striking a fact that the Ludlow is generally regarded as extending into the Devonian,—the American records in this being the assumed standard. Mr. Hall takes this ground.

The group of Cyathophylloid corals is much more largely developed in the Ludlow beds than in the American Silurian; for the coral-reef period in America is that of the Upper Helderberg in the Lower Devonian. Besides, there is the higher group of Fishes, the first of the Vertebrates, some relics of which occur in the upper layers of the Ludlow beds. These remains are of the genera *Cephalaspis*, *Onchus*, and *Plectrodus*: the first belongs to the tribe of Ganoids, and the other two to that of the Selachians or Sharks. In the same Ludlow beds, traces of land-plants have been found, in the shape of minute globular bodies which have been regarded as the seed-vessels of some species of the Lycopodium tribe of plants. The upper part of the Silurian beds in Bohemia has also afforded fish-remains of similar character to those of the Ludlow beds.

If the Ludlow beds be divided and the upper part referred to the Devonian, then these species of fishes and the associated land-plants will come into that age,—the Age of Fishes.

Still, if fossil fishes should hereafter be found even lower in the Silurian, it will harmonize entirely with the system in other parts of the geological series. As has been stated on p. 126, we naturally look for precursors of every Age. There were Mammals before the age of Mammals, Reptiles before the age of Reptiles, Acrogens and

Conifers before the age of Coal-plants; and so there may have been Fishes precursors of the age of Fishes. This is consonant with the principles involved in the very nature of history.

European geology, as far as developed, sustains the conclusions deduced from the American:—that the Upper Silurian era, to its close (with the exception above mentioned, if it be such), was an era of small areas of dry land,—of continents mostly submerged, though not necessarily at great depths,—of warm waters to the poles,—of marine life,—of Mollusks and inferior Crustaceans as the higher life of the seas, and the flower-like Corals and Crinoids as the inferior life, and of Sea-weeds as the vegetation.

AGE OF FISHES, OR DEVONIAN AGE.

The Devonian formation was so named by Murchison from Devonshire, England, where it occurs, and abounds in organic remains. Both in America and other countries the beds pass into those of the Silurian by an easy transition. Yet they still mark a new epoch in the progress of life, and thus stand apart in the system of geological history.

The periods and epochs in the American Devonian, as deduced from the series of rocks laid down by the New York geologists, are as follow:—

5. CATSKILL PERIOD (12).........	Catskill Red Sandstone (12).
4. CHEMUNG PERIOD (11)......	2. *Chemung epoch*—Chemung group (11 *b*).
	1. *Portage epoch*—Portage group (11 *a*).
3. HAMILTON PERIOD (10)....	3. *Genesee epoch*—Genesee beds (10 *c*).
	2. *Hamilton epoch*—Hamilton group (10 *b*).
	1. *Marcellus epoch*—Marcellus group (10 *a*).
2. CORNIFEROUS PERIOD (9).	3. *Upper Helderberg epoch*—Upper Helderberg group (9 *c*).
	2. *Schoharie epoch*—Schoharie grit (9 *b*).
	1. *Cauda-Galli epoch*—Cauda-Galli grit (9 *a*).
1. ORISKANY PERIOD (8).........	Oriskany sandstone.

The formations of the first and second periods are sometimes designated the Lower Devonian, and those of the third, fourth, and fifth periods, the Upper Devonian. The Corniferous period was the great limestone-making period of the Devonian age in America. The rocks of the succeeding periods (Upper Devonian) are mostly shales or sandstones, with only subordinate layers of limestone.

1. ORISKANY PERIOD (8).

I. Rocks: kinds and distribution.

The Oriskany sandstone is named from the town of Oriskany, in Oneida co., N.Y., one of its localities. The rocks are mostly rough sandstones. They are 30 feet thick in this region, and thin out both to the east and west, being barely recognizable on the Hudson, and to the west extending as far as Cayuga Lake. West of the Appalachians, beyond New York, the formation is for the most part unknown; but *along the Appalachian region* it stretches south through Pennsylvania, Maryland, and Virginia, having a thickness of several hundred feet, and retaining its rough aspect; and it also occurs to the north at Gaspé, near the Gulf of St. Lawrence. In the *Eastern border region*, the formation has been identified by its fossils in Maine between Parlin Pond and the Aroostook River, and elsewhere; also in Nova Scotia.

The sandstone consists either of pure siliceous sands, or of argillaceous sands. In the former case it is usually yellowish or bluish, and sometimes crumbles into sand suitable for making glass, as at Vernon, N.Y. In the latter it is of a dark brown or reddish color, and was once evidently a sandy or pebbly mud. In some places it contains nodules of hornstone. The beds are often distinguished by their rough and hard dirty look (especially after weathering) and the large coarse calcareous fossil shells,—species of Brachiopods. The sandstone occurs in Cayuga co., Canada West, and also on the Mississippi in Illinois. In St. Genevieve co., Missouri, the rock is a limestone (Shumard).

The Nova Scotia strata of this epoch occur at Nictaux and on Moose and Bear Rivers. They include a thick band of fossiliferous iron-ore, which is an argillaceous deposit at Nictaux, but, owing to partial metamorphism, is a magnetic iron-ore on Moose River.

II. Life.

1. *Plants.*

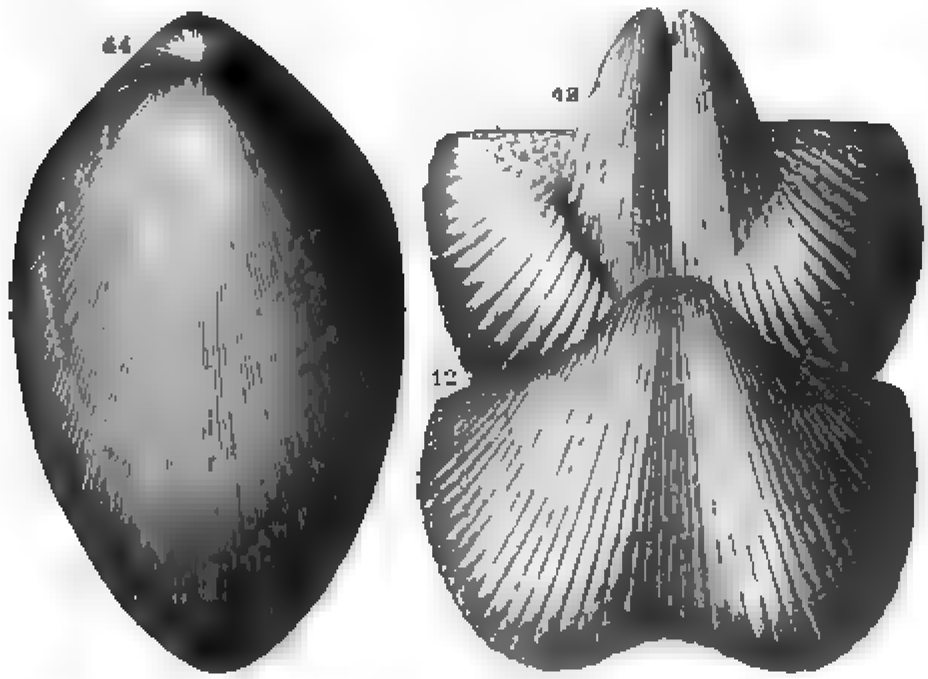
No remains of land-plants have been yet observed. Considering the nature of the rock, the negative evidence bears strongly against the existence of land-vegetation in the Oriskany period.

The rocks of Gaspé, according to Dawson, contain relics of Coniferous wood and other plants, and are pronounced to be probably Lower Devonian; but the particular period to which they belong is not known. They are mentioned beyond, under the Hamilton period. According to the same author, remains of land-plants occur in a limestone at Gaspé, which "seem," he observes, "to indicate the occurrence of *Psilophyton* and *Noeggerathia* or *Cordaites* in the Upper Silurian of Canada."

2. *Animals.*

The most common species are the coarse *Spirifer arenosus* (fig. 442), and the *Rensselaeria ovoides* (fig. 444). The rock is often made up

Figs. 442–444.



BRACHIOPODS.—Figs. 442, 443, Spirifer arenosus; 444, Rensselaeria ovoides.

of these large fossil shells crowded together, or contains their casts with the cavities the shells once occupied. Fig. 443 represents a cast of the interior of *Spirifer arenosus*.

In New York, the fossils include *Brachiopods* (which are the most numerous species), *Conchifers, Gasteropods, Cephalopods* (*Orthocerata*, etc.), and *Trilobites*, and only traces of Crinoids. In Maryland, according to Hall, there are a number of fine Crinoids of the genera *Mariacrinus, Edriocrinus*, and others, besides three species of *Cystideans*, and among them one of the peculiar genus *Anomalocystis* (allied to fig. 418). Among the Gasteropods of the same region there are great numbers of shells of the genus *Platyceras*,—a thin conical shell having the top rolled to one side (like fig. 458), related apparently to *Janthina* of our seas. In some places in Maryland and Virginia, they occur packed crowdedly together in a soft sand-rock, the sands of which are hardly more coherent than those of a sea-beach (Hall). This rock contains a wonderful profusion of shells, although the number of species is small. The ribs of some of the *Spirifers* have a peculiarity observed in only one American *Silurian* species (of the Niagara epoch), but in Europe not known before the *Devonian* age,—which is, that they subdivide dichotomously, instead of being simple.

The shell in the genus *Rensselaeria* Hall, contains a loop-like arm-support, a little like that in *Terebratula*, but it is only curved, instead of bent, and has a spade-shape termination.

III. General Observations.

The Oriskany sandstone is another of the arenaceous rocks ranging from central New York to the southwest along the Appalachian region, and thus serving to define the old Appalachian sand-reef. This it does not only to the south, but also to the northeast at Gaspé. As in other cases, the rock thickens on going from New York to the southward, showing less depth of water and less change of level, or subsidence towards the Azoic, than in the opposite direction. The limits of the formation in the State of New York, and its fossils also, seem to point to the existence at this epoch of a sheltered bay opening to the southeast,—such a New York bay as might have existed if the Green Mountain region (as before in the Upper Silurian era) were raised a dozen feet or more out of water, and if also the Azoic of northern New Jersey (see p. 137), the proper continuation of the Green Mountains, were an island or reef in the sea. The muddy and sandy bottom of the bay would have given the shells a fit place for growth. To the south, as the fossils in Maryland and beyond show, the accumulations were those of an open bay or coast, where there were at least purer waters.

The thickness of the formation along the Appalachian region indicates a continuation of the series of subsidences that began far back in the Silurian or before. We may hence conclude that the Green Mountain region was a narrow island lying between seas covering more or less of New England and New York, and bounded by the St. Lawrence channel on the north; for there is no reason to doubt that Devonian as well as Carboniferous strata occur among the now crystalline rocks of New England. The region of Appalachian subsidence, instead of including the Green Mountains, as in the early Lower Silurian era, extended northward, in the direct line of the Alleghanies, over the southern half of central New York, as in parts of the Upper Silurian; for this is indicated by the position of the sandstone.

The Oriskany period, taking into view the whole range of its life, is more closely related, as Hall states, to the last period of the Silurian than to the following Devonian; but in its more common Brachiopods it has rather a Devonian character. It was fixed upon as the beginning of the American Devonian by the eminent French geologist M. de Verneuil. There is, however, a more complete change in the American fauna after the Oriskany period than before it: for this reason, and on account of the relations of its fossils to those of the Lower Helderberg, Hall suggests the query whether the Devonian age would not more properly commence with the next or Corniferous period.

2. CORNIFEROUS PERIOD (9).

Epochs.—1. CAUDA-GALLI, or that of the Cauda-Galli grit (9 *a*); 2. SCHOHARIE, or that of the Schoharie grit (9 *b*); 3. UPPER HELDERBERG, or that of the Onondaga and Corniferous limestones (9 *c*).

I. Rocks: kinds and distribution.

1. CAUDA-GALLI EPOCH.

The term Cauda-Galli refers to the feathery forms of an abundant fossil supposed to be the impressions of a sea-weed (fig. 441). The rock is a drab or brownish argillaceous sandstone, often shaly and crumbling. It rests upon the Oriskany sandstone, but its position is somewhat more easterly, it lying altogether east of the west limit of Oneida co., N.Y., and thickening towards the Hudson.

In the Helderberg Mountains, south of Albany, the thickness is 50 or 60 feet. It extends southerly, and has been observed in Sussex co., New Jersey, and on the eastern border of Pennsylvania, with its characteristic *Cauda-galli* fossil.

2. SCHOHARIE EPOCH.

The Schoharie grit is a fine-grained calcareous sandstone, containing numerous fossils. The lime becomes dissolved out on exposure, leaving a rusty rock full of casts of the fossils and holes left by the removed shells. In New York the beds are confined to the eastern part of the State. It resembles the Oriskany sandstone, but has very different fossils.

3. UPPER HELDERBERG EPOCH.

The rocks of the Upper Helderberg epoch are limestones. They spread widely over the *Interior Continental basin* from eastern New York to the States beyond the Mississippi.

The formation in New York is divided into the *Onondaga* limestone (the lower part) and the *Corniferous* limestone (the upper). The latter contains disseminated masses of hornstone (or imperfect flint), lying in layers of the limestone between other layers that contain little or no hornstone (just as the flint lies in the chalk-bed); and hence the name *corniferous* (from the Latin *cornu, horn*). The thickness of the whole series of strata is in some places 350 feet.

The color of the limestone is dark grayish and occasionally black in New York, and light gray, drab, and buff in the Mississippi basin.

(*a.*) *Interior Continental basin.*—In New York the beds have a thickness seldom over 20 feet for the Onondaga limestone and 50 feet for the Corniferous. The

formation has been recognized in Ohio, along the shores of Lake Erie, in Michigan, Indiana, Illinois, Kentucky, Wisconsin, Iowa, Missouri, and other parts of the Mississippi basin, but the subdivisions above mentioned are not distinguishable. In the Michigan peninsula the thickness is 354 feet (Winchell); in Iowa, 50 to 60 feet (Hall); in Missouri, from a few feet to 75. The rocks are finely displayed at the Falls of the Ohio, near Louisville, Ky., and are as full of fossil corals as any modern coral reef.

The upper layers of the rock in New York, which are usually dark grayish, are nearly black on the Niagara. In some localities west of New York the rock is oolitic. In Missouri, siliceous and sandstone layers alternate with the limestone. The hornstone of the Corniferous beds is often left in rough projecting masses where the limestone portion has been worn away by the action of water. These rocks outcrop also in southwestern Canada, N. of Lake Erie.

(*b.*) *Appalachian region.*—The Upper Helderberg formation has not been observed among the rocks of Pennsylvania except northwest of the Kittatinny Mountain, between the Delaware and Lehigh Rivers.

(*c.*) *Eastern border region.*—At Owl's Head, on Lake Memphremagog, near the northern borders of Vermont, there is a true coral-reef rock, full of corals, overlaid by talcose schist; and, although partially metamorphic, many of the specimens of fossils are tolerably perfect. Among the species, Billings has recognized *Syringopora Hisingeri* B., *Favosites basaltica* Goldfuss, *Diphyphyllum stramineum* B., and *Zaphrentis gigantea* Lesueur. Besides these, according to Hitchcock, *Atrypa reticularis* has been identified by Hall. To the south, in Massachusetts, at Bernardston (west of the Connecticut, and not far from Greenfield), there is also a metamorphic limestone of this epoch, with fossils (Hitchcock). It is altogether probable that Devonian beds stretch south from Lake Memphremagog; for the rocks have this *strike* through the whole length of the State (and through New England generally); and the limestone may be represented among them,—perhaps in the Calciferous mica schist, which Hunt has suggested may be a metamorphic limestone. It is also supposed that the Upper Helderberg limestone occurs south of the St. Lawrence, between Vermont and Gaspé.

II. Life.

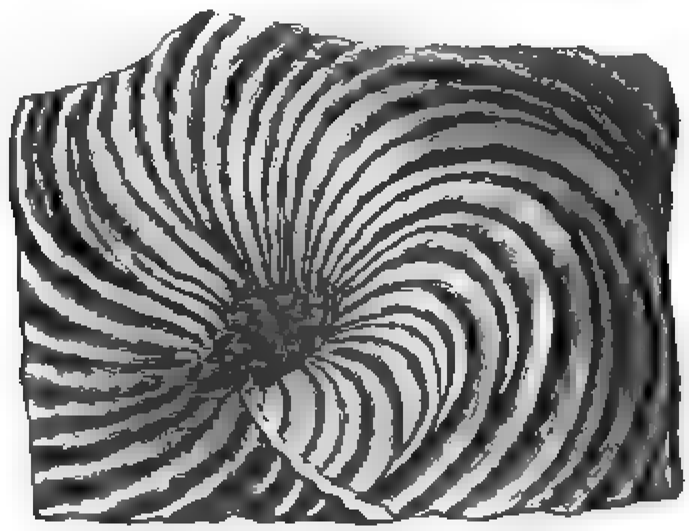
1. *Plants.*

The plants thus far observed are sea-weeds and Protophytes. No land-plants of the period are known. Fig. 441 represents the "Cauda-Galli" sea-weed characteristic of the first epoch.

The protophytes occur in the hornstone of the Corniferous limestone, and appear to be very abundant throughout it. The discoveries were made, but a few days before these pages were printed, by Dr. M. C. White, of New Haven. Through his investigations, and others, since made, by F. H. Bradley, it is now known that organisms similar to those figured below (fig. 441 A) are common to the hornstone of both older and later Palæozoic periods. The

facts show that hornstone is analogous to flint in origin as well as in its mode of occurrence: the two are the same in composition

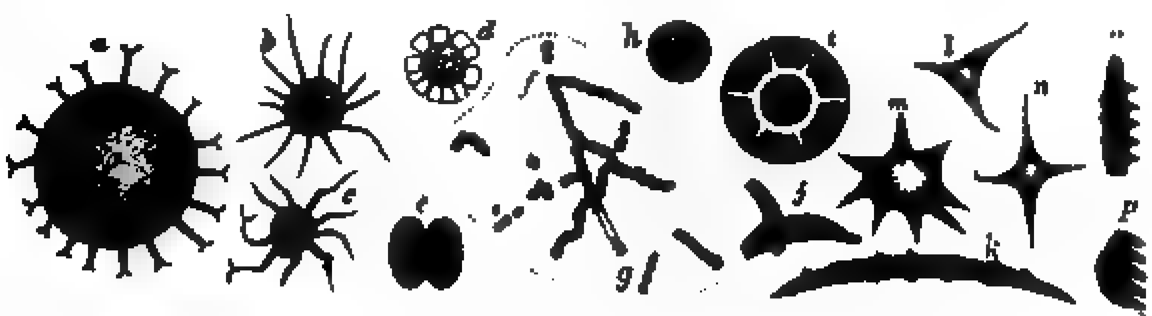
Fig. 441.



Fucoides Cauda-Galli

(page 55). Figs. 441 A *a–d* represent the sporangia (spore-capsules, or receptacles containing the germinative cells) of Desmidieæ, or

Fig. 441 A.



MICROSCOPIC ORGANISMS IN HORNSTONE.—Figs. *a–i* and *l–n*, Protophytes; *j, k*, Spicula of Sponges; *o, p*, fragments of dental apparatus of Gasteropods.

Desmids,—closely resembling organisms from flint called *Xanthidia* by Ehrenberg;—*e*, a Desmid having the usual division into halves; *f, g*, Desmids consisting of several cells; *i*, a Diatom:—figures magnified about 225 diameters. The sizes of the specimens figured vary from 1-500th to 1-5000th of an inch: diameter of fig. *a*, 1-500th in.; of *d, e*, 1-1500th; of *i*, 1-1000th; of cells in *f, g*, 1-7000th by 1-5000th. Desmids, like the Diatoms, are microscopic plants, consisting of one or a few cells: but they secrete little or no silica, and have a pale-green color. The hornstone also contains numerous rhombic crystals, probably of calcite, from 1-500th to 1-1000th inch in diameter.

2. *Animals.*

The Upper Helderberg period is eminently the coral-reef period of the Palæozoic ages. Many of the rocks abound in corals (see figs. 445–451), and are as truly coral reefs as the modern reefs of the Pacific. The corals are sometimes standing in the rocks in the position they had when growing; others are lying in fragments as they were broken and heaped up by the waves; and others were reduced to a compact limestone by the finer trituration before consolidation into rock. This compact variety is the most common kind among the coral-reef rocks of the present seas; and it often contains but few distinct fossils, although formed in waters that abounded in life. At the Falls of the Ohio, near Louisville, there is a magnificent display of the old reef. Hemispherical Favosites five or six feet in diameter lie there nearly as perfect as when they were covered with their flower-like polyps; and, besides these, there are various branching corals, and a profusion of *Cyathophylla*, or cup-corals; some of the species of the latter (fig. 445) have a breadth of three inches, and one of six or seven inches; and when alive the expanded polyp must have had at least this diameter, or, with the expanded tentacles, probably an inch or two more. These ancient corals may have had the same rich and varied colors that characterize the Zoophytes of our own epoch.

There is another point in which the Corniferous period stands out prominently in American Palæozoic history. *It contains the earliest remains, thus far discovered, of fishes,—the first of the sub-kingdom of Vertebrates.* The life of the American seas from this time, therefore, included species of all four sub-kingdoms, *Radiates*, *Mollusks*, *Articulates*, and the branch now added, *Vertebrates*.

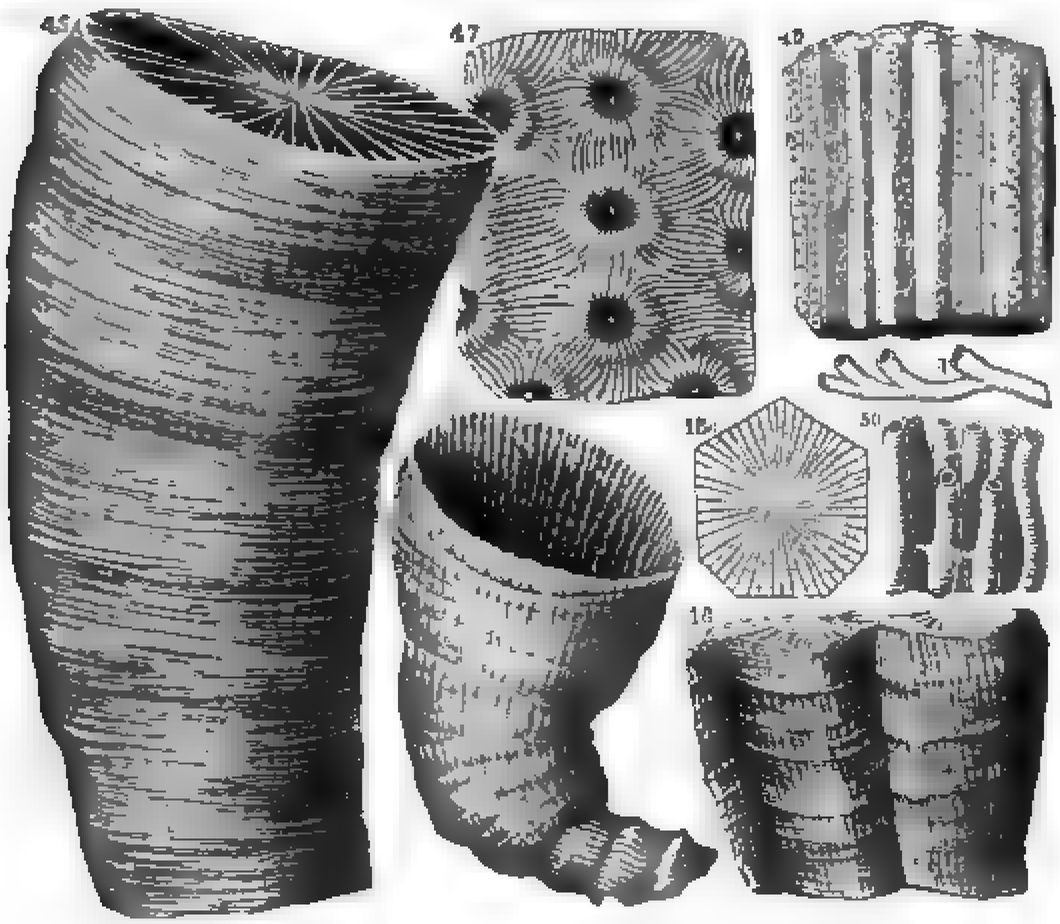
Among Brachiopods the new genus *Productus* makes its first appearance, one that afterwards in the Carboniferous age became very common: its earliest species are but half an inch in breadth, while some of the later are three or four inches. Figs. 228, 229, page 183, represent different species, but not those of this period.

The hornstone contains spicula of Sponges, two of which are figured in 441 A *j*, *k*; *k* is magnified 75 diameters. Along with these, White has detected a fragment of the dental apparatus of a Gasteropod, represented in fig. *o*. Fig. *p* is from a specimen of this kind observed in hornstone of the Black River limestone (Trenton period), Watertown, N.Y., by Bradley; Desmids and spicula of Sponges accompany it. The organic origin of the Palæozoic hornstone can hardly be doubted.

Characteristic Species.

1. **Radiates.**—(*a.*) *Polyps.*—Fig. 445, *Zaphrentis gigantea*, part of a large specimen from the Falls of the Ohio, showing at top the radiate structure, and

Figs. 445–451.



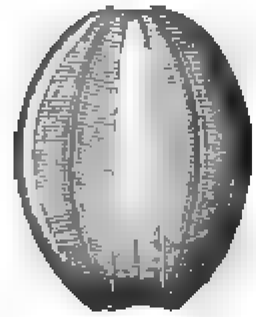
POLYPS.—Fig. 445, Zaphrentis gigantea; 446, Z. Rafinesquii: 447, Phillipsastrea Verneuilli; 448, 448 *a*, Caryophyllia rugosa; 449, Favosites Goldfussi; 450, Syringopora Maclurii, 451, Aulopora cornuta.

the depression or fossette in the star on one side; fig. 446, *Zaph. Rafinesquii* E. & H., from the Falls of the Ohio, remarkable for the depth of the cell. Another Cyathophylloid coral of the genus *Chonophyllum* (*C. magnificum* B.) has a diameter at top of six or seven inches it is from Walpole, Canada West. Fig. 447, *Phillipsastrea Verneuili* E. & H.; fig. 448, *Caryophyllia rugosa*, a fragment from a large mass from the Falls of the Ohio; 448 *a*, section of a cell, showing the numerous and very thin rays; fig. 449, *Favosites Goldfussi* D'Orb., from the Falls of the Ohio, a fragment of a large specimen; fig. 450, *Syringopora Maclurii* B., from Canada West, a coral consisting of a cluster of small tubular cells; fig. 451, *Aulopora cornuta* B., from Canada.

(*b.*) *Acalephs.*—No species are known, unless. as Agassiz has suggested, the Favosites and related corals are of this class (p. 162).

(*c.*) *Echinoderms.*—There are many species of Crinoids, and the large, smooth stems of some of them are half an inch to an inch in diameter. The species of most interest are the *Nucleocrini* (also called *Olivanites*); they are representatives of the Pentremite family,—a group which had its first species in the Chazy, the early part of the Trenton period, in the Lower Silurian, but which from that time appears to have been extinct until the Corniferous period in the Devonian. In the Subcarboniferous period it was very common. The species of this period are ovoidal, or like an olive in shape, and have ambulacral areas closely like those of the true (pentagonal) Pentremites (figs. 531, 532). Fig. 452 is the *Nucleocrinus Verneuili.* (The name *Nucleocrinus* of Conrad antedates *Olivanites* of Troost, as well as *Elæacrinus* of Rœmer.)

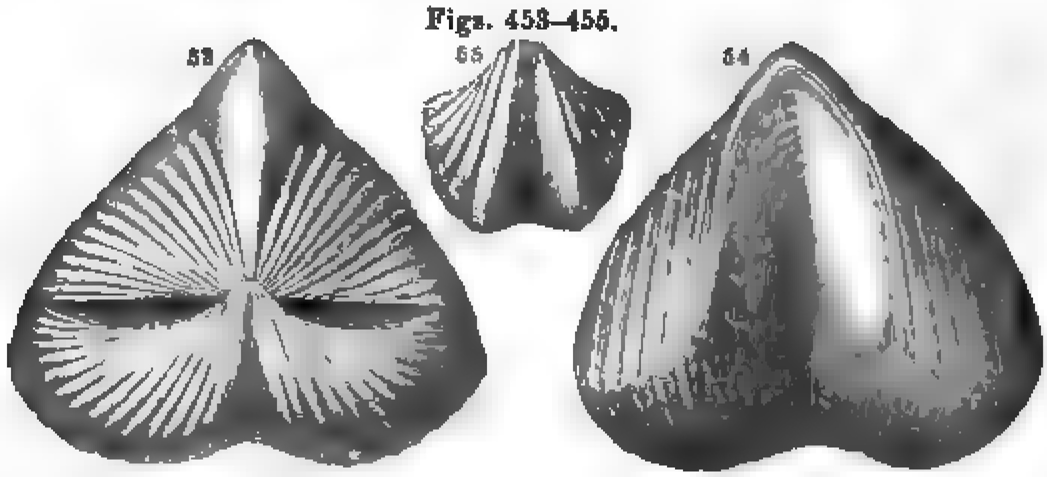
Fig. 452.



Nucleocrinus Verneuili.

2. **Mollusks.**—(*a.*) *Brachiopods.*—Figs. 453 and 454, *Spirifer acuminatus* Con. (*S. cultrijugatus* Rœmer), from New York and the West. Fig. 455, *Spirifer*

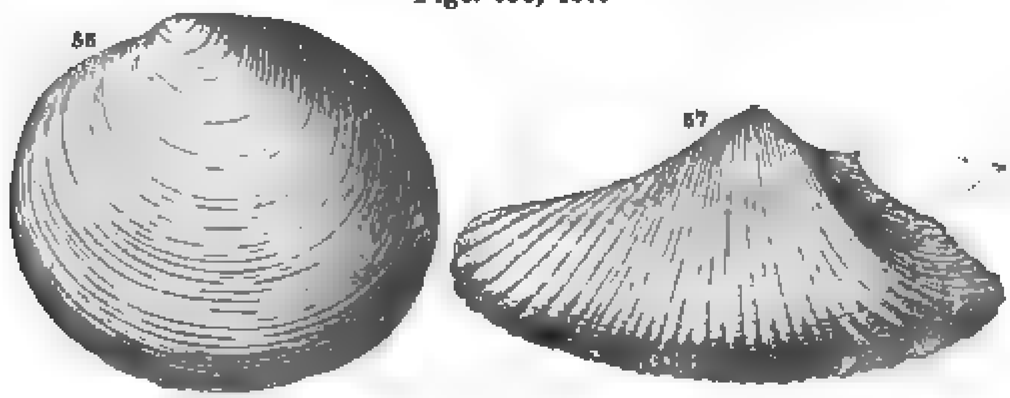
Figs. 453–455.



Brachiopods.—Figs. 453, 454, Spirifer acuminatus; 455, Sp. gregarius.

gregarius, very common in Indiana and Kentucky, at the Falls of the Ohio, and at Middleton, Canada (Billings). Also, *Pentamerus aratus*, *Chonetes hemisphe-*

Figs. 456, 457.



Conchifers.—Fig. 456, Lucina? proavia; 457, Conocardium trigonale.

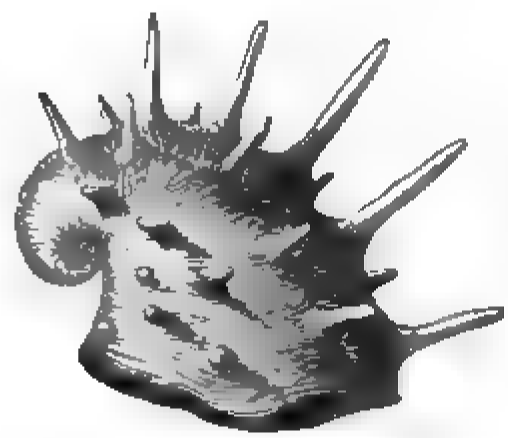
rica, *Atrypa reticularis*, *A. impressa*, *Stricklandia elongata* (Billings), formerly *Pentamerus elongatus* Vanuxem; also a *Calceola* near *C. sandalina* (fig. 231),

found in Tennessee; it is a third American genus of the Terebratula family, —*Stricklandia* and *Rensselaeria* being the first two. Two small species of *Productus* have been collected by Billings in Canada, and one by Jewett in the New York Corniferous.

(*b.*) *Conchifera.*—Fig. 456, *Lucina? proavia*, also occurring in Europe; fig. 457, *Conocardium trigonale* of both New York and the West.

(*c.*) *Pteropods, Gasteropods,* and *Cephalopods.*—Pteropods are represented by the *Tentaculites scalaris*. There are also several species of Gasteropods. Fig. 458 is the *Platyceras dumosum* of the Corniferous in New York.

Fig. 458.



Platyceras dumosum.

A few Orthocerata occur in the beds. The *Cyrtoceras undulatum*, a large shell coiled in a plane, is supposed, as the name implies, to be related to the Cephalopods.

3. **Articulates.**—Trilobites are the only Articulates known. The most common species are the *Dalmania* (*Odontocephalus*) *selenurus*, having a two-pointed tail; and the *Proetus* (*Calymene*) *crassimarginatus*, having the posterior margin of the body (the pygidium) thickened and rounded.

The Schoharie grit is closely related in its fossils to the limestones above, and contains but few species that are not found in the latter.

4. **Vertebrates.**—The remains of the earliest of Vertebrates, Fishes, appear first in America, according to present knowledge, in the Schoharie grit; and many species are known from the later epoch of the Corniferous period, both in New York and the more western States of Ohio, Indiana, etc. Some of these remains are represented in the annexed figures. Fig. 459 is the fin-bone of a large shark; fig. 460, the head of a fish related closely to the *Pterichthys* of Stromness, drawn by Dr. Newberry from a specimen found at Sandusky, Ohio; and fig. 461, the tooth, natural size, of probably this formidable species. Dr. Newberry estimates its length at six or seven feet. A specimen was earlier found by Dr. Norwood at Madison, Indiana, and named by Owen & Norwood *Macropetalichthys* (Am. Jour. Sci. [2] i. 367, 1846). It is near the genus *Homostius* described by Mr. Asmuss, of Dorpat, in 1833 and 1837. As shown in the figure, the genus differs widely in the sutures of the buckler from *Pterichthys* (fig. 516). *Asterolepis* of Eichwald has the priority of *Pterichthys*; but it was based on a fragment only, and was published without a description.

Fig. 459.

Fin-spine of a shark (× ½).

There are also among the remains in the Corniferous beds species of *Cephalaspis* resembling the European (fig. 517), and of *Holoptychius* (near fig. 518); but no figures of them have yet been published.

Fig. 460. Fig. 461.

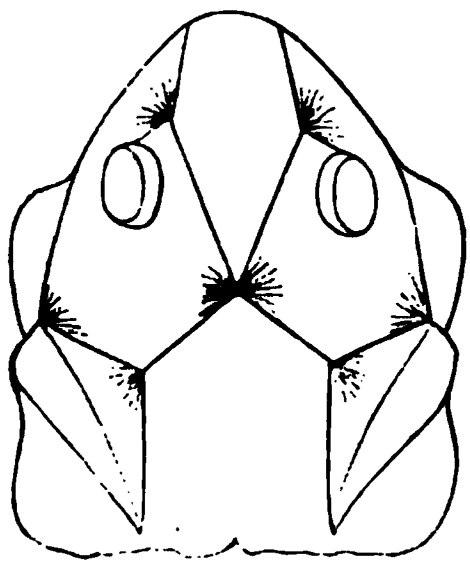


Fig. 460, Head of Macropetalichthys Sullivanti Newberry (× ¼); 461, Tooth of same.

These earliest of American fishes belong to two out of the three grand divisions of the class:—

First, the *Sclachians*, or sharks.

Secondly, the *Ganoids*, or fishes having the body covered with shining bony scales or plates. This order of Ganoids, once exceedingly numerous in species, is now nearly extinct: it is represented by the Gar-pike and Sturgeon of existing waters.

The third grand division—that of the common osseous fishes, or *Teliosts*, which includes the Perch, Salmon, etc.—was not introduced until near the close of the Reptilian age, in the Cretaceous period.

The Selachians of the Devonian age belong to the *Cestraciont* family of sharks,—a group in which the mouth is furnished with a pavement of large bony plates instead of teeth, and which have the first ray of the dorsal fin a large and stout spine (figs. 464, 470).

The Devonian Ganoids are of three kinds:—(1) *Placoganoids*, having the body covered with plates instead of scales (like fig. 516); (2) *Rhombifers*, having rhombic scales, and these arranged like tiles (as in figs. 473, 475, 519); and (3) *Imbricates*, having the scales arranged like shingles, as in *Holoptychius* (fig. 518) and other *Cœlacanths*, and the modern *Amia*.

All these ancient fishes have *vertebrated tails*,—that is, the vertebral column extends to the extremity of the tail (figs. 519, 603), instead of stopping short at its commencement (fig. 473) as in nearly all existing fishes. In most of these vertebrate-tailed species the vertebral column extends into the *upper* lobe of the tail, and the two lobes are very unequal, as in figs. 464, 519, 617:

these have been thence called *heterocercal* fishes, while those having a tail of the ordinary form, as in fig. 473, are said to be *homocercal.**

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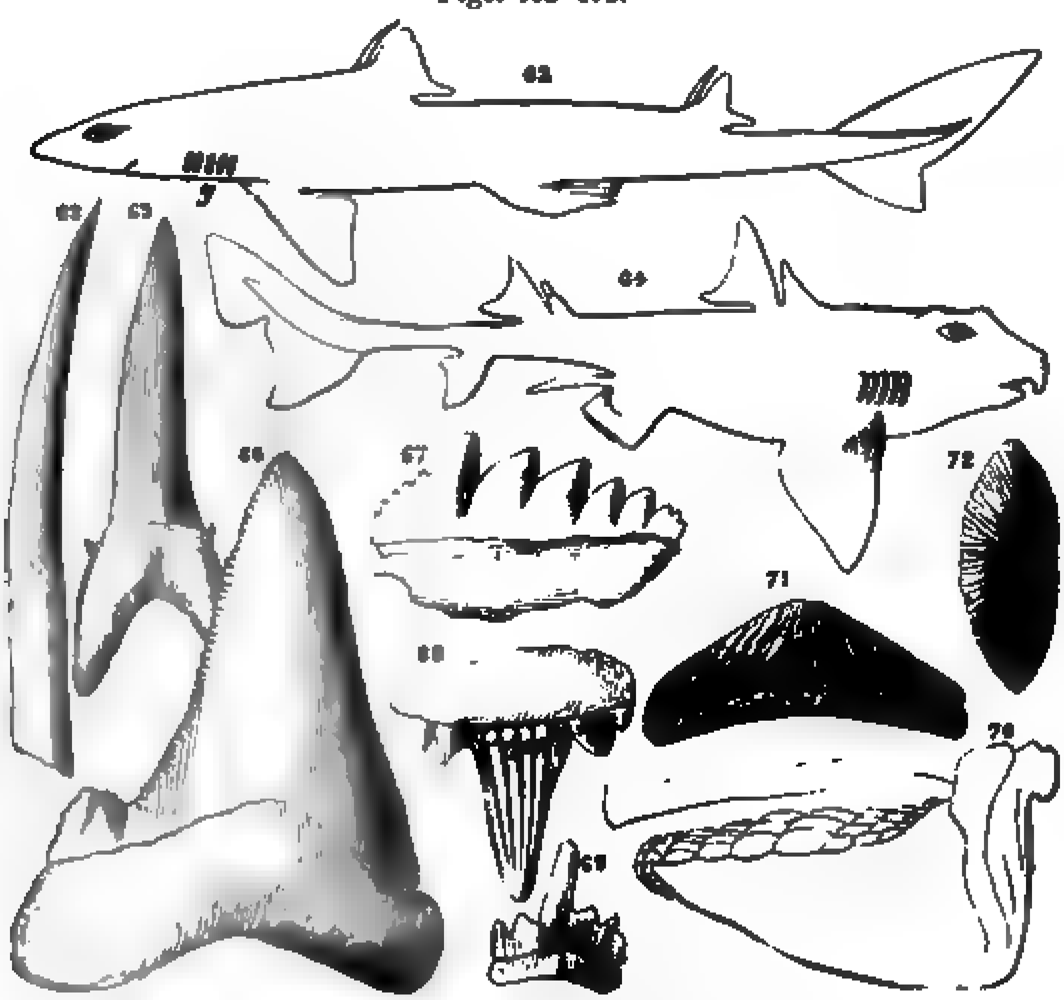
* FISHES.—A systematic review of the class of Fishes will make the subject more intelligible. The relations of Fishes to other Vertebrates are mentioned on p. 152. Fishes (excluding a few abnormal kinds of the group *Dermopteri*) are divided into three orders:—

I. SELACHIANS (or *Placoids*).—Include the Sharks (figs. 462, 464) and Rays, having (1) the skeleton cartilaginous; (2) the body covered usually with a harsh skin; (3) the gills attached by both margins, and the gill-openings without opercula (*g*, fig. 462); (4) the *optic nerves not decussating*. The term

Figs. 462–472.



SELACHIANS.—Fig. 462, Spinax Blainvillii (× ⅙): 463, Spine of anterior dorsal fin, natural size; 464, Cestracion Philippi (× ⅙); 465, Tooth of Lamna elegans; 466, Tooth of Carcharodon angustidens; 467, id. Notidanus primigenius. 468, id. Hybodus minor; 469, id. Hyb. plicatilis; 470, Mouth of Cestracion, showing pavement-teeth of lower jaw; 471, Tooth of Acrodus minimus; 472, id. Acrodus nobilis.

Selachian—proposed by Cuvier, and now used by Agassiz—is from the Greek σέλαχος, *cartilage*, while Placoid is from πλάξ, *a plate*. The rough skin is often

III. General Observations.

Geography.—In the first epoch of this period, that of the Cauda-Galli grit, the beds were, as a body, more easterly in position over

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called *shagreen*, and may sometimes be seen to be composed of minute rhombic or angular pieces, each rising into a point at centre.

II. GANOIDS.—Include the modern and ancient *Gars* (figs. 517–519), and the *Sturgeon*, having (1) the skeleton cartilaginous or bony; (2) the gills as in ordinary fishes; (3) the body covered with *bony* plates or scales (figs. 474, 475), which are usually shining or enamel-like in surface; (4) the *optic nerves not decussating*. The name Ganoid is from γανος, *shining*, and alludes to the scales.

III. COMMON OR OSSEOUS FISHES, or TELIOSTS.—The Perch, Salmon, and all common fishes are here included. (1) The skeleton is bony, as the name *Teliost*—from τελειος, *complete*, and οστιον, *bone*—implies; (2) the gills have one margin free; (3) the scales covering the body are membranous; (4) the *optic nerves decussate*. The *Cycloids* of Agassiz have the scales unarmed with sharp points (fig. 476); while the *Ctenoids* (from κτεις, *a comb*) have them armed (fig. 477): but this subdivision is not a natural one.

1. Selachians.—The Selachians are divided into three groups, the *Squaloids*, or Sharks, the *Rays*, and the *Chimæroids*. The Squaloids have an elongate body, with the gill-openings lateral; the Rays, a broad, flat body, with the gill-openings in the ventral or under surface; the Chimæroids, only one gill-opening, besides other peculiarities.

The *Squaloids* include,—

(1.) The *True Sharks*, or *Squalodonts*, having sharp-edged teeth (figs. 465–467), and the mouth on the under surface of the head (fig. 462).

(2.) The *Hybodonts*, having teeth nearly like the preceding, but with the edge less acute: they are intermediate between the Squalodonts and the Cestracionts (figs. 468, 469).

(3.) The *Cestracionts*, having a rough pavement of bony and usually enamelled pieces in the mouth, and the mouth situated at the extremity of the head; fig. 464, *Cestracion Philippi* or "Port Jackson Shark," Australia; 470, side-view of mouth, showing the pavement or grinding surface of lower jaw, with the pointed teeth at the opening; 471, 472, different views of the pavement-pieces in the Cestraciont genus *Acrodus*. In the genus *Cochliodus* the number of pavement-pieces is very small, and they are proportionally large (figs. 546, 547), besides having a spiral twist. These Cestraciont mouths were well fitted for masticating Ganoids and shell-fish.

The *Chimæroids*, including the living *Chimæræ* and several extinct species, have two to four osseous plates to either jaw in place of teeth.

Among the Rays, *Myliobates* and species of some related genera use their large pectoral fins in swimming, instead of the tail, and the motion is much like that of flying through the water,—so that they are sometimes called *Sea-Eagles*. The mouth in this group is paved with four- or six-sided plates, evenly and neatly joined.

New York than those of the preceding period. In the Schoharie epoch they were still farther to the east than the Cauda-Galli grit; at the same time they continue to be sandstones. But with the next epoch there was a change. The continent from eastern New

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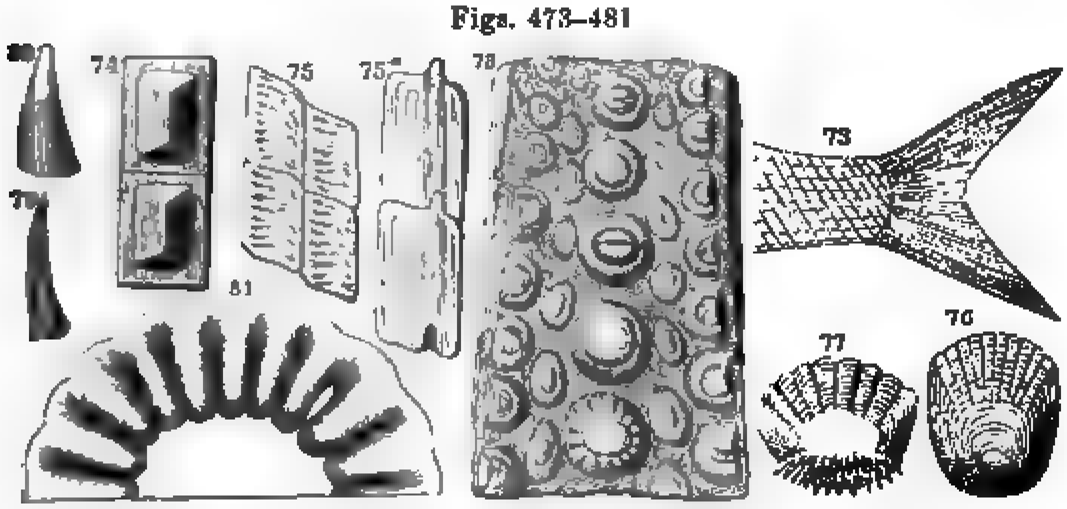
In several genera of Selachians the dorsal fin is armed at its anterior margin with a large spine. In the genus *Spinax* (fig. 462, reduced) there are such spines, one to each dorsal fin; fig. 463 represents one of natural size for a fish (*Spinax*) about 2½ feet long.—Such spines exist also in the *Cestracionts* (fig. 464), the *Hybodonts*, and *Chimæroids*. In these Squaloid groups the spine is usually laterally compressed, and if denticulate it is so along the posterior margin. In *Trygon* and some other genera among the Rays, there is a similar spine, but it is flattened in a direction transverse to the body, and has both outer edges denticulate, when either is at all so. These spines in some ancient fishes were two feet or more in length (see fig. 557). In a living *Cestracion*, 23 inches long, it is 1½ inches in length.

2. **Ganoids.**—The following are the principal subdivisions of Ganoids:—

A. Placoganoids.—In these the body has a case or coat of mail, of large enamelled plates, like that of a turtle. (1.) The *Coccosteids* have a fish-like tail, and swim by means of it: Ex., *Coccosteus*. (2.) The *Pterichthyds*, or "winged fishes" (as the term signifies), have no caudal fin for swimming, but, instead, a pair of powerful paddles (pectoral fins): Ex., *Pterichthys* (fig. 516). Thus there are sculling and paddling Placoganoids, as well as Rays.

B. Scale-covered Ganoids, or Lepidoganoids.—They have the body covered with scales set on either like tiles or like shingles, and on this difference two subdivisions are based. *Lepidoganoids* is from λεπις, *a scale*, and *ganoid*.

Figs. 473–481



Ganoids (excepting 476, 477).—Fig. 473, Tail of Thrissops (× ½); 474, Scales of Cheirolepis Traillii (× 12); 475, id. Palæoniscus lepidurus (× 6); 475 *a*, under-view of same; 476, Scale of a Cycloid; 477, id. of a Ctenoid; 478, part of pavement-teeth of Gyrodus umbilicus; 479, Tooth of Lepidosteus; 480, id. of a Cricodus; 481, Section of tooth of Lepidosteus osseus.

(*a.*) *Rhombifers, or Ordinary Ganoids.*—The scales are rhomboidal or rectangular, bony, usually thick, shining, and enamelled, and set on like tiles (figs.

York westward became to a large extent covered with coral-growing seas. The wide distribution of the rocks proves the vast area of those coral seas. It also teaches that they were shallow seas; for, as already remarked, corals grow and form limestones only where they are within the reach of the waves. The Upper Helderberg period was eminently the coral-reef period in Palæozoic history.

Climate.—The question of the occurrence of rocks of this period in the Arctic is not yet decided. It is probable that they exist there, on North Somerset and elsewhere, judging from the fossil corals and Brachiopods (Am. Jour. Sci. [2] xxvi. 120). Among the former, besides the *Favosites Gothlandica* (Upper Silurian in Europe), there are *Heliolites porosa*, and *Cyathophyllum helianthoides*, Devonian species occurring in Europe and America.

This identity of species between the Arctic, and Europe and America, just illustrated, favors an approximate identity of climate: there is no sufficient evidence of a cold Arctic, or even of a wide diversity of zones.

HAMILTON PERIOD (10).

Epochs.—1. MARCELLUS, or that of the Marcellus shale (10 *a*); 2. HAMILTON, or that of the Hamilton beds (10 *b*); 3. GENESEE, or that of the Genesee shale (10 *c*).

474, 475). Fig. 475 *a* shows the under surface of 475, and illustrates the manner in which the scales are locked together. Among them there are (1) the *Cephalaspids*, having a broad buckler-head; Ex., *Cephalaspis* (fig. 517); and (2) the *Sauroids* (figs. 473 and 519), having the form of ordinary fishes, and sharp, though sometimes very small, teeth. Figs. 479, 480 are teeth (nat. size) of a *Lepidosteus*, and a *Cricodus*. Other genera of this group are *Dipterus*, *Cheirolepis*, *Palæoniscus*, etc. The *Lepidoids* of Agassiz are here included.

(*b.*) *Imbricates.*—Scales not rhombic, imbricate or set on like shingles, as in *Holoptychius* (fig. 518) and the modern *Amia*.

The *Pycnodonts* are Rhombifers, having smooth pavement-teeth. Fig. 478 represents part of the pavement-teeth in a species of *Gyrodus*.

C. ACIPENSEROIDS.—Include the modern Sturgeon, which has a cartilaginous skeleton, large rounded plates, and no teeth.

Labyrinthine structure of Ganoid teeth.—The teeth in the Sauroids, or at least in many of them, have a labyrinthine structure within. This structure is illustrated in one of its simplest forms in fig. 481, which is an enlarged section, by Agassiz, of the tooth of a living Lepidosteus. It consists in a folding inward of the enamel and dentine. In fig. 480 the striæ of the tooth correspond to these inward foldings.

I. Rocks: kinds and distribution.

The rocks in the eastern United States are either shales or sandstones, with some thin limestone beds. Shales especially abound in the State of New York.

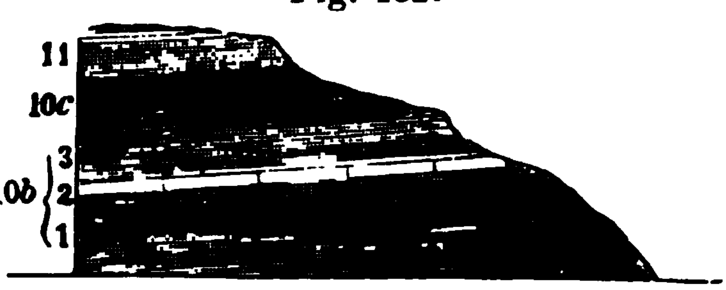
The *Marcellus shale* (10 *a*) is for the most part a soft, argillaceous rock. The lower part is black with carbonaceous matter, and contains traces of coal or bitumen, so as sometimes to afford flame in the fire. The *Hamilton beds* (10 *b*) in New York (so named from Hamilton, Madison co., N.Y.) consist of shales and flags, with some thin limestone beds. The excellent flagging-stone in common use in New York and some adjoining States, often called North-River flags, comes from a thin layer in the Hamilton. The *Genesee shale* (10 *c*) is a blackish shaly rock overlying the Hamilton.

The Hamilton formation spreads across the State of New York, having its northern limit along a line running eastward from Lake Erie. The greatest thickness—about 1200 feet—is east of the centre of the State. It extends southwest into Pennsylvania and Virginia, and also westward, as a thin rock, mainly of limestone, through parts of Michigan (at Mackinac), Illinois (at Rock Island, etc.), Iowa (New Buffalo, etc.), Missouri, and elsewhere. Beds probably of this period occur also in Maine, and near Gaspé.

(*a.*) *Interior Continental basin.*—In the lower part of the Marcellus shale (the rock of the first epoch) in New York, there are also layers of concretions of impure limestone, and these abound most in fossils. But the fossils of the shale are generally small.

The *Hamilton beds* consist of shales separated into two parts by a thin layer of *Encrinal* limestone, and in many places overlaid by a thin limestone stratum called the *Tully limestone*. In the annexed section from the coast of Lake Erie (as given by Hall), the Hamilton beds, 10 *b*, include (1) blue shale; (2) Encrinal limestone; (3) Upper or Moscow shale: the Tully limestone is wanting. Above lie (10 *c*) the Genesee slate; and (11) a part of the Portage group of the next (Chemung) period.

Fig. 482.



Section of Hamilton beds, Lake Erie.

The flagging-stone of the Hamilton is quarried near Kingston, Saugerties, Coxsackie, and elsewhere on the Hudson in Ulster, Greene, and Albany cos., N.Y., and also near Cayuga Lake. The bed is but a few feet thick. It breaks into very even slabs of great size. It is almost without fossils, but is penetrated in many parts by the filling of a slender worm-hole. The Genesee slate overlies the Tully limestone when this is present. It is not recognized in the eastern part of the State of New York.

The Marcellus shale rarely exceeds in thickness 50 feet. The Hamilton strata are 1000 feet thick in central New York, but not half this along Lake Erie. They are also comparatively thin and more sandy on the east in the Helderberg Mountains. They are well exposed along the valleys of Seneca and Cayuga Lakes. The Genesee shale is 150 feet thick near Seneca Lake; it thins westward, and is not over 25 feet on Lake Erie.

Still farther west it is represented by what is called the *Black slate*,—rather a shale,—a very persistent stratum occurring in Tennessee, Kentucky, Indiana, and elsewhere; it is a hundred feet thick at Louisville, Ky., and in Indiana. In Missouri, the Hamilton formation consists of about 50 feet of shale, with some beds of limestone.

b. Appalachian region.—In Pennsylvania, H. D. Rogers makes three divisions of the Hamilton formation, a lower of black shales, which is 250 feet thick in Huntingdon, a middle of variegated shales and flags, 600 feet thick at the same place, and an upper black shale of 300 feet.

The thickness of the Hamilton formation east of central New York shows that this region was at this time, as in the Oriskany period, on the northern border or limits of the Southern Appalachian region.

At Gaspé, on the Gulf of St. Lawrence, the Devonian sandstones have a thickness of several thousand feet. They are regarded as belonging to the Lower rather than Upper Devonian; but the precise age has not been determined. From the fossil plants it seems probable that the Hamilton period is represented among them.

c. Eastern border.—At Perry, Maine, there are other Devonian strata connected with the Canada deposits, and they also may be of the Hamilton series. The fossils thus far found have not served to fix their precise age. They contain some species of fossil plants identical with those of Gaspé.

Ripple-marks.—The rocks of this formation, especially the Hamilton beds, are remarkable for the abundance of *ripple-marks* on the layers. The flagging-stone is often covered with ripple-marks and wave-lines. The *joints* intersecting the strata are often of great extent and regularity. They have been referred to on page 100, and a sketch is there given representing a scene on Cayuga Lake. The rock at the place is the Moscow shale.

II. Life.

1. *Plants.*

The carbonaceous material of the black Marcellus shale is mostly due to vegetation; but whether to sea-weeds or land-plants has not been ascertained. In the Hamilton beds the evidence of verdure over the land is no longer doubtful. The remains show that there were trees, and of large size. Figs. 483 and 484 represent the outer surface of two of the species, showing the scars left by the bases of the fallen leaves. Fig. 483 is *Lepidodendron primævum*, from near

Huntingdon, Pa., and fig. 484, a *Sigillaria*, from Otsego co. and other places in New York. The first is related, and probably both, to the *Lycopodia* (Ground-Pine) of modern damp woods. The largest of living *Lycopodia* are three to four feet in height. These earliest representatives of the type had trunks a foot or more in diameter, and may have been more than a score of feet in height. These plants are covered with leaves much like Pines and other Conifers; and the stem in fig. 484 resembles that of a Spruce, stripped of its leaves. In the Devonian of the vicinity of Gaspé, near the Gulf of St. Lawrence, there is true Coniferous fossil wood, according to Dawson.

Fig. 483. Fig. 484.

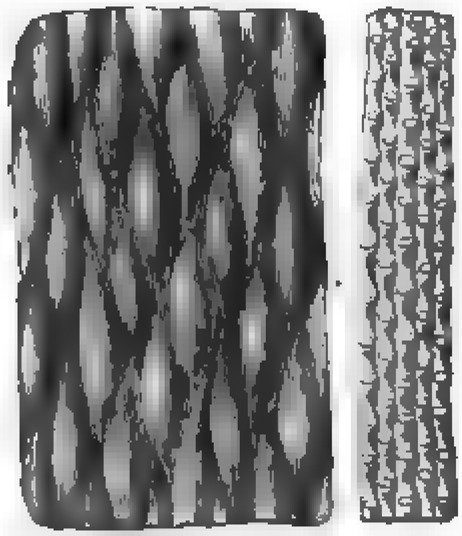


Fig. 483, Lepidodendron primævum; 484, Sigillaria.

For remarks on the subdivisions of Plants, see page 165. On the frontispiece, representing a Carboniferous landscape, the stump in the right corner is a *Sigillaria;* the highest tree in the same corner is a *Lepidodendron*, and the smaller plants near it, having stems covered with short leaves, are other Lycopodiaceous species; the high tree in the left corner is also a *Lepidodendron;* the tree towards the middle of the view is a *tree-fern*, and the spreading leaves at its foot are the fronds of low ferns.

The Coniferous plant of Gaspé is named by Dawson *Prototaxites Logani*. In the same formation there are also the following species of the Lycopodium tribe:— *Lepidodendron Gaspianum* Dawson, *Psilophyton princeps* Dawson, *Cordaites angustifolia* Dawson, and the fern *Cyclopteris Jacksoni*. These four species occur also at Perry, Me., together with a species of *Sternbergia*, which, according to Dawson, is probably the pith of a Coniferous tree of the genus *Dadoxylon*, a subdivision of *Araucarites*.

The relics of sea-weeds are common; and one of the most abundant is related to the *Fucoides Cauda-Galli* (fig. 441). It is sometimes a foot in diameter.

2. *Animals.*

The animal remains of the Marcellus are comparatively few, and, excepting the Goniatites, generally small: their small number corresponds with the fact that the rock is a fine shale. In the Hamilton beds, which are coarser and often resemble a consolidated mud-bed, fossils are much more numerous. With the

Genesee slate there is a return to the fineness of the Marcellus, and also in part to some of the same species of shells.

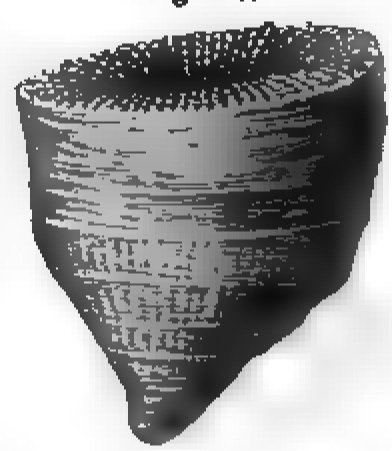
The preceding period had abounded in corals, and hence in limestones; in the Hamilton, when the condition was unfavorable for coral reefs over New York and south, there were still some fine species of corals and Crinoids, but the predominant fossils were Brachiopods and Conchifers,—species that live on muddy bottoms. There were many broad-winged Spirifers, among which the *Sp. mucronatus* (fig. 489) was very common. The limestone layers mark an occasional change to clearer waters, when Crinoids and corals had a chance to flourish.

With this period commence the earliest of *Goniatites* (fig. 498),—a group of Cephalopods with Nautilus-like shells, but differing from *Nautilus* in having the siphuncle dorsal, and the septa with one or more flexures at the margin; in case of one flexure or more, there is always one on the dorsal margin, as in fig. 498 *a*. The Goniatites became more and more complex in the flexures of the septa during the following periods of the Palæozoic, and afterwards were replaced by the Ceratites and Ammonites, to which they are closely related.

Characteristic Species.

1. **Radiates.**—Fig. 485, the Coral *Heliophyllum Halli*, common in the Hamilton at Moscow, York, and elsewhere, and found also in England. The Encrinal limestone is made up of fragments of crinoidal columns.

Fig. 485.



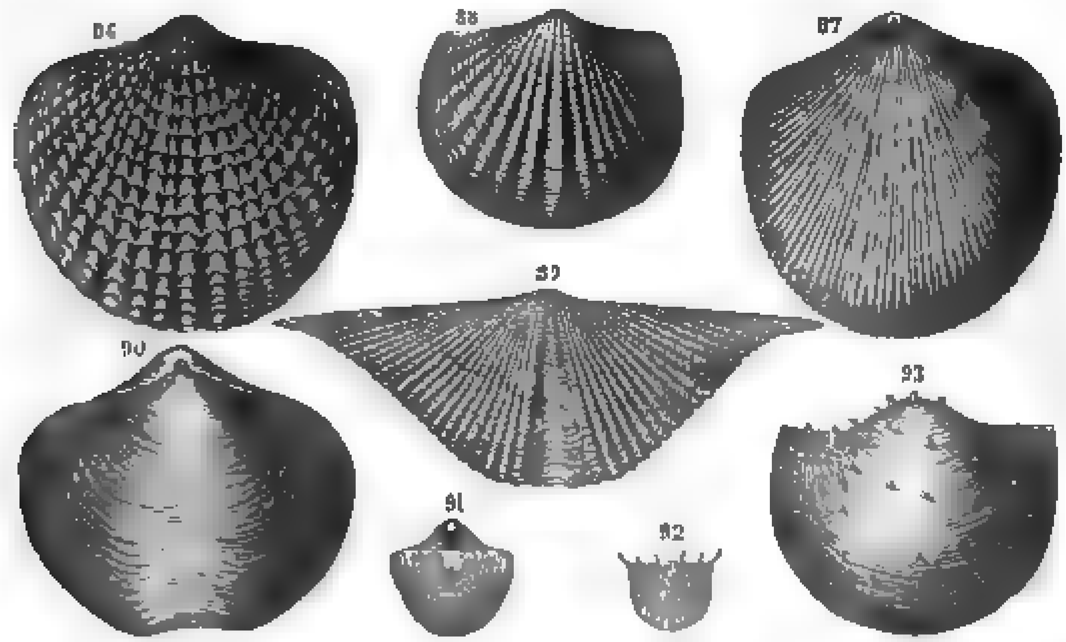
Heliophyllum Halli.

2. **Mollusks.**—(*a.*) *Brachiopods.*—Fig. 486, *Atrypa aspera*, also European; 487, *A. reticularis*, regarded as the same species as that of the Corniferous period, but usually much larger and fuller, being sometimes nearly two inches broad; 488, *Tropidoleptus carinatus*, in New York, Illinois, Iowa, Europe; 489, *Spirifer mucronatus*, very common; 490, *Athyris spiriferoides* (*Atrypa concentrica* of Conrad),—it has the spire internally of a Spirifer; 491, *Spirifer* (*Martinia*) *umbonatus*, also European; 492, *Chonetes setigera*, found in both the Marcellus and Genesee shales; 493, *Productus subalatus*, Rock Island, Ill. A shell closely like the *S. umbonatus*, but higher, occurs in Iowa and Illinois, and is named *Cyrtia umbonata* by Hall. *Spirifer granuliferus* is a large Hamilton species, having a granulated surface.

(*b.*) *Conchifers.*—The species are often of large size, but none yet described have a sinus in the pallial impression. Fig. 494, *Orthonota undulata* Con.; 495, *Avicula Flabella*; 496, *Grammysia Hamiltonensis*,—also European, in the Eifel; 497, *Microdon bellistriatus* Con.

(*c.*) *Gasteropods.*—A few species have been described. They are all without a beaked aperture, like those of older time. The *Bellerophon patulus* is a broad species of the genus, with a flaring aperture.

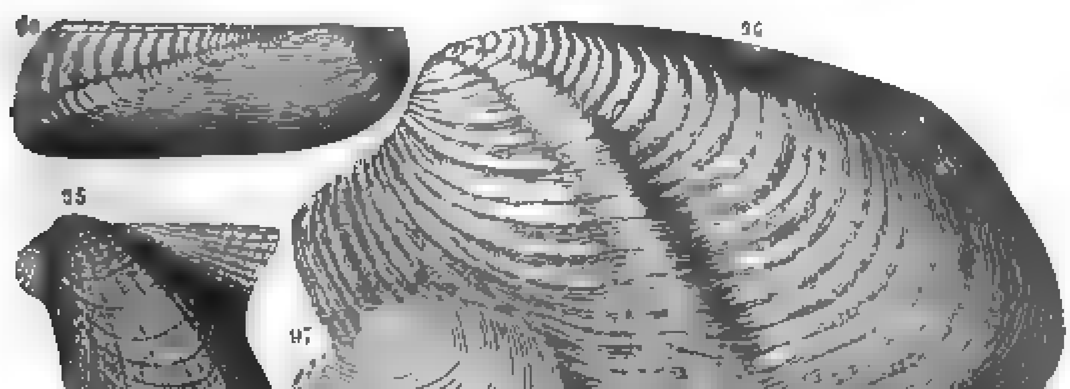
Figs. 486–493.



Brachiopods.—Fig. 486, Atrypa aspera; 487, A. reticularis; 488, Tropidoleptus carinatus; 489, Spirifer mucronatus; 490, Athyris spiriferoides; 491, Spirifer (Martinia) umbonatus; 492, Chonetes setigera; 493, Productus subalatus.

(*d.*) *Cephalopods.*—Fig. 498, *Goniatites Marcellensis* Van., a species sometimes a foot in diameter, occurring in the Marcellus shale. Two small species, the

Figs. 494–497.

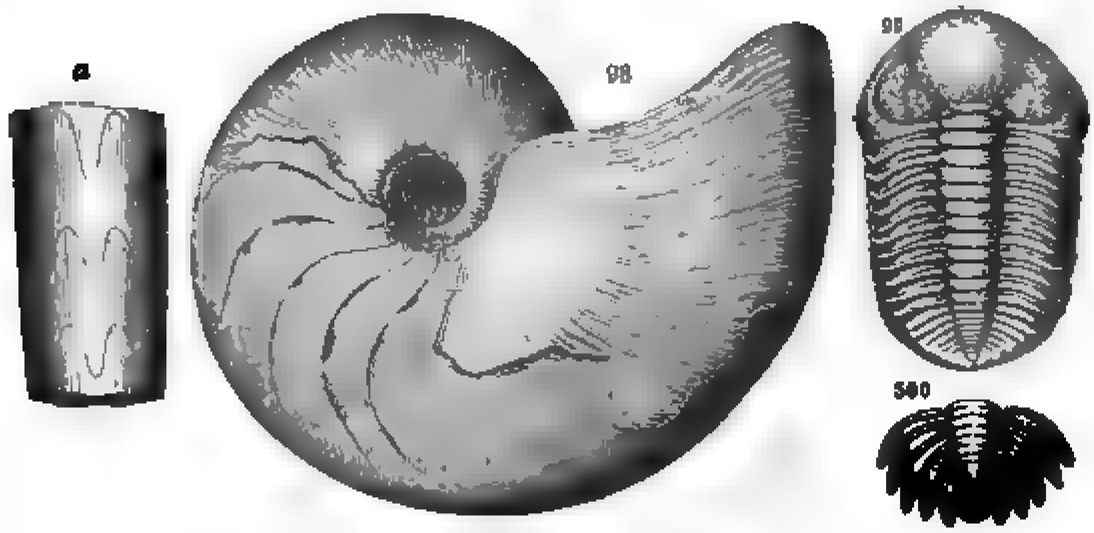


Conchifers.—Fig. 494, Orthonota undulata (× ⅔). 495, Avicula Flabella (× ½); 496, Grammysia Hamiltonensis, 497, Microdon bellistriatus.

G. uniangularis and *G. punctatus*, are reported by Conrad from the Hamilton beds. The genus *Orthoceras* is represented by a few species of moderate size.

3. Articulates.—(*a.*) *Crustaceans.*—The Trilobites *Phacops Bufo* (fig. 499) and *Dalmania calliteles* (fig. 500, representing the posterior extremity) are common in the Hamilton beds.

Figs. 498–500.



CEPHALOPOD.—Fig. 498, Goniatites Marcellensis. TRILOBITES.—Fig. 499, Phacops Bufo; 500, Caudal extremity of Dalmania calliteles.

(*b.*) No *Insects* are known, although the land had its vegetation.

General Observations.

Geography.—The positions and nature of the Hamilton beds indicate similar geographical conditions to those of many earlier periods, that a shallow sea covered New York and spread widely to the west, and that many changes were experienced in the water-level; the beds are to a great extent mud-beds, whence we learn that they were deposited in quiet waters; the fossils are marine, proving marine waters. The beds in New York are thickest about its central parts, and yet spread to its eastern and western limits, excepting the Upper, the Genesee shale, which is not known in the eastern part; they are partly calcareous in the lower part of the Marcellus beds, proving that the change from the condition of the limestone-making Corniferous period was gradual; limestone layers occur higher up, at intervals, indicating changes of level, which favored at times Encrinites and corals; ripple-marked flags make up some layers, proving by their evenness and extent, and the regularity of the lamination, that the sea at the time of their formation swept over extensive sand-flats, coming in over the present region of the Hudson River or of New York Bay. The existence of a barrier of sand along the ocean, such as is thrown up and at intervals removed again by the waves, would account for the vary-

ing conditions and also for changes in the living species by extermination.

Moreover, while these mud-accumulations were here in progress, there were Hamilton limestones forming in some of the Western States, indicating again the existence of the interior or Mississippi sea,—a feature in a large part of both Silurian and Devonian geography.

The Appalachian region is still an area of vastly the thickest deposits, and hence of the greatest change of level by subsidence; and the great thickness of the formation (1000 feet) in central New York makes it another example of the prolongation of the subsiding Appalachian region northward over southern New York. This fact and the thinning of the beds towards the Hudson indicate that the Green Mountain region was at least a few feet above the sea, so that the great New York bay, alluded to in the observations on the Oriskany beds, was still outlined on the east, although communicating westward more or less perfectly with the interior basin.

Life.—The land-plants of the Hamilton beds prove that the rocks and soil of the emerging continent and its islands were not then barren wastes, whatever their earlier condition. There were forests of Conifers and Lepidodendra, besides smaller plants, but no Palms or Angiosperms (p. 165).

CHEMUNG PERIOD (11).

Epochs.—1. PORTAGE, or that of the Portage group (11 *a*); 2. CHEMUNG, or that of the Chemung group (11 *b*).

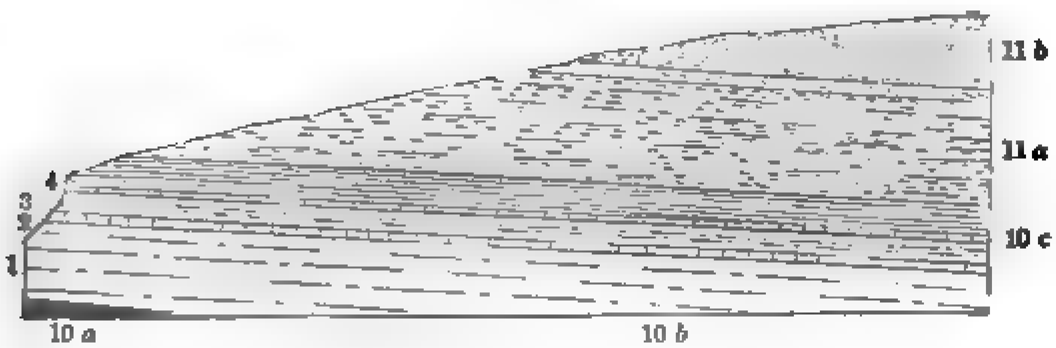
I. Rocks: kinds and distribution.

Portage epoch.—The Portage group consists of shales and laminated or shaly sandstones. In western New York, on the Genesee River, the lower beds are the Cashaqua shales; next, the Gardeau shales and flagstones; then, above these, the thick Portage sandstones. But going westward the shales increase in proportion, and eastward the sandstones greatly predominate, the subdivisions not continuing distinct; there are also changes in the fossils corresponding with these variations.

The rocks have a thickness of 1000 feet on the Genesee River, and 1400 near Lake Erie. (Hall.) They are well developed about Cayuga Lake, but have not been recognized in the eastern half of the State of New York.

Chemung epoch.—The Chemung group extends widely over the southern tier of counties of New York, and consists of sandstones and coarse shales in various alternations. The thickness has been estimated at 1500 feet near the longitude of Cayuga Lake, and less towards Lake Erie and beyond

Fig. 501.



Section of rocks of the Hamilton and Chemung Periods.

In this section, from one by Hall, taken in Yates co., N.Y., 10 *a*, 10 *b*, 10 *c*, are rocks of the Hamilton period; *a*, the Marcellus shale; *b*, the Hamilton group; *c*, the Genesee slate; and in the Hamilton group, 2 is the Encrinal limestone, and 4 the Tully limestone; 11 *a* is the Portage group, 11 *b* the Chemung group.

Westward of New York the Portage and Chemung groups have been supposed to be represented in Ohio by a sandstone called "*Waverly sandstone*," three to four hundred feet in thickness. Many facts, however, point rather to the conclusion that the larger portion at least of this series really belongs to the Subcarboniferous, or is at any rate newer than the Chemung. Late investigations also render it more than probable that beds referred to the Chemung in Missouri and Iowa are really more recent.

To the south and southwest of New York, in Pennsylvania, and beyond along the *Appalachian region*, the corresponding beds have great thickness, amounting in some places to more than 3000 feet. The rocks have the same sandstone character as in New York. This remark applies to the beds in the northeast towards Gaspé; for the Upper Devonian is represented in that part of the continent. The beds at St. John's, New Brunswick, have been specially referred to the Upper Devonian, but their precise parallelism with the New York Devonian has not been determined.

The beds of both the Chemung and Portage groups in New York and Ohio abound in ripple-marks, obliquely-laminated layers, mud-marks, and cracks from sun-drying,—evidences of the existence of extensive exposed mud-flats, of sandy or muddy areas swept by the waves, and of tidal currents in contrary movement through the shallow waters.

II. Life.

The Chemung period was as profuse in life as any that preceded it, and yet was almost wholly different in its species from the Hamilton.

1. *Plants.*

Besides the *Cauda-Galli* Sea-weed, there are remains of many land-plants; and thus we find that after the first appearance of an unequivocal land-plant their relics are no longer rare fossils.

Figs. 502–504.

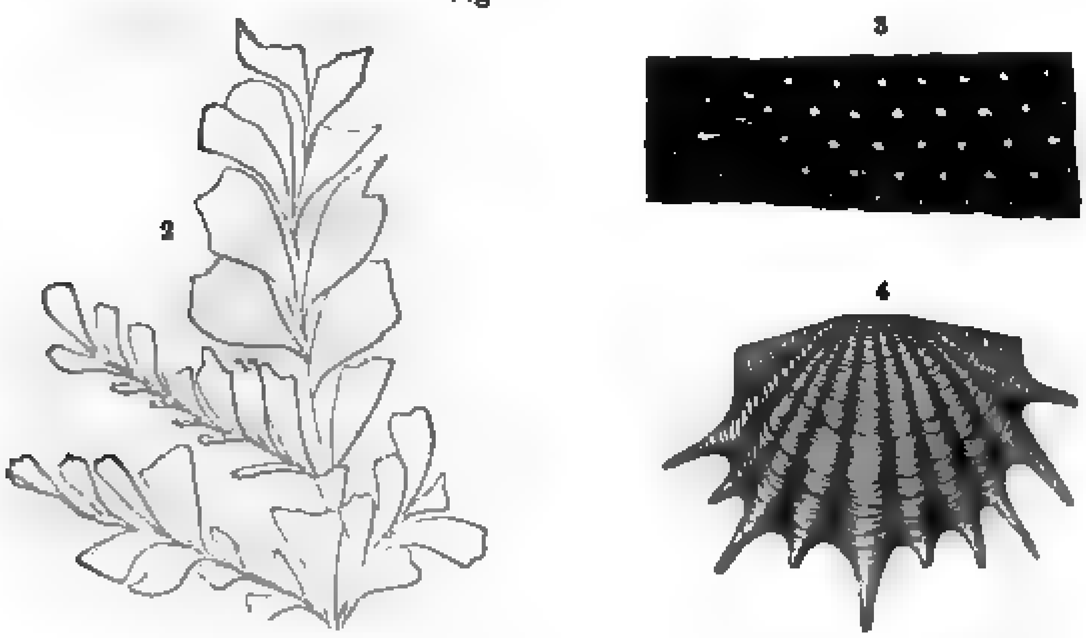


Fig. 502, Sphenopteris laxus; 503, Lepidodendron Vanuxemi; 504, Atrypa Hystrix.

In the Portage there are great numbers of *Fucoids*, or forms regarded as fucoidal. The most common kind appear like short, straight, simple stems, two or three inches long, scattered thickly over the surface of the flagstones. In the Upper Portage there are other cylindrical forms penetrating vertically the layers; but these are probably the fillings of worm-holes, analogous to those of the Potsdam sandstone (p. 185).

2. *Animals.*

The Portage beds, though abounding less in fossils than the Chemung, contain various species of *Crinoids*, *Brachiopods*, *Conchifers* (*Aviculopectens*, *Aviculæ*, and others), *Bellerophons*, and *Goniatites*. A large Crinoid—the *Cyathocrinus? ornatissimus*—occurs in great numbers, broken to fragments, through a small area in the town of Portland, on Lake Erie.

The Chemung group in New York affords great numbers of *Aviculæ*, many Brachiopods, including broad-winged *Spirifers*, and some *Producti*, a huge *Goniatite* (four or five inches in diameter), and rarely a *Trilobite*.

Characteristic Species.

1. *Plants.*—Fig. 502, *Sphenopteris laxus*, Upper Chemung beds; *Sagenaria Chemungensis*, from near Elmira, N.Y.; 503, *Lepidodendron Vanuxemi*, from near Owego, N.Y. Species of *Calamites* have also been found. At St. John's, New Brunswick, occur the following species, first described, with one exception, by Dawson:—the *Dadoxylon Ouangondianum* (a Conifer), *Calamites Transitionis* Goeppert, *Asterophyllites parvula*, *Sphenophyllum antiquum*, *Lycopodites Matthewi*, *Cordaites Robbii*, a *Sphenopteris*, *Cyclopteris Jacksoni*, and others. The *Cyclopteris* occurs also at Perry, Maine.

Figs. 505–507.

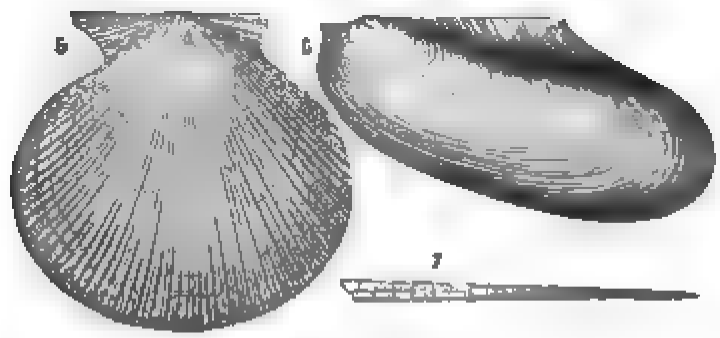


Fig. 505, Aviculopecten duplicatus; 506, Pteronites? Chemungensis; 507, Orthoceras Acicula.

2. *Animals.*—Fig. 504, *Atrypa Hystrix*; Fig. 505, *Aviculopecten duplicatus*; Fig. 506, *Pteronites? Chemungensis*; Fig. 507, *Orthoceras Acicula*.

III. General Observations.

Geography.—The character of the beds—the shales that were made from mud-beds and the shaly sandstones from sand-depositions—which spread over western and southern New York and southwest along the Appalachian region, which become more shaly to the western limit of the State and more sandy in the opposite direction, tells nearly the same story with regard to the geography of the continent as in the Hamilton period. The rocks were largely shallow-water or sand-flat formations, as shown by the ripple-marks, shrinkage-cracks, and oblique lamination; and they therefore indicate by their great thickness a subsidence during their progress to a corresponding extent, and, further, that this subsidence or change of level affected most the Appalachian region. The shallow sea probably extended westward, forming sandy deposits over Ohio, though of much less thickness than in New York.

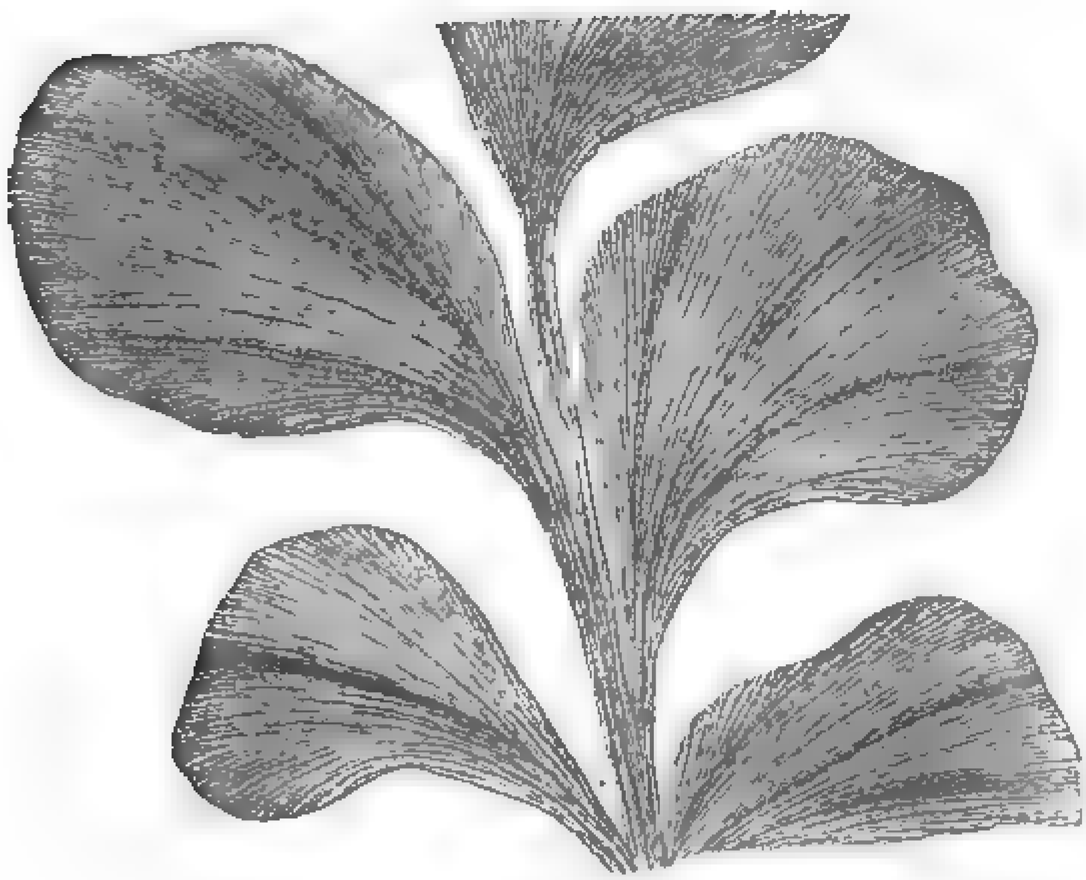
Life.—In its plants the Chemung period indicates the approach of the Carboniferous age,—the genera *Lepidodendron*, *Sagenaria*, *Sphenopteris*, *Calamites*, being characteristic of that time. Its animal species bear marks of new progress, in the great *Goniatites*, with more complex septa, and the greater abundance of large-winged Spirifers, as well as the occurrence of species having spinous shells.

CATSKILL PERIOD (12).

I. Rocks: kinds and distribution.

The rocks of the Catskill period are shales and sandstones of various colors, in which red predominates. The sandstones are far more extensive than the shales, and pass into conglomerates or coarse grit-rock, and also into a rough mass looking as if made of

Fig. 507 A.



Noeggerathia obtusa.

cemented fragments of hard slate. The upper part is in general a conglomerate. There are ripple-marks, oblique lamination, and other evidences of sea-shore action, in many of the strata. Some of the layers are partially calcareous.

The formation, instead of thickening to the westward in New York, like those preceding it in time, thins out in that direction, and thickens towards the Hudson, being two or three thousand feet in the Catskills. It stretches south along the Appalachian region, beneath the Coal formation of Pennsylvania and Virginia, where it is 5000 or 6000 feet thick. It is eminently an *Appalachian* formation.

II. Life.

The rocks afford but few relics of animal life, and these differ completely from those of the earlier periods. There is thus, as appears, a new beginning in the life of the continent. It is, however, yet uncertain what were the condition and life of the interior region, as no strata have been there recognized as certainly of this era.

1. *Plants.*—The land-plants, relics of which are occasionally met with, were of the same Carboniferous character as in the Chemung period. *Fig. 507 A*

Fig. 508.

Modiola angusta.

represents a portion of a large frond of the *Noeggerathia obtusa*, from Montrose, Pa.,—a characteristic fern of the period. The frond was over a foot broad.

Figs. 509–511.

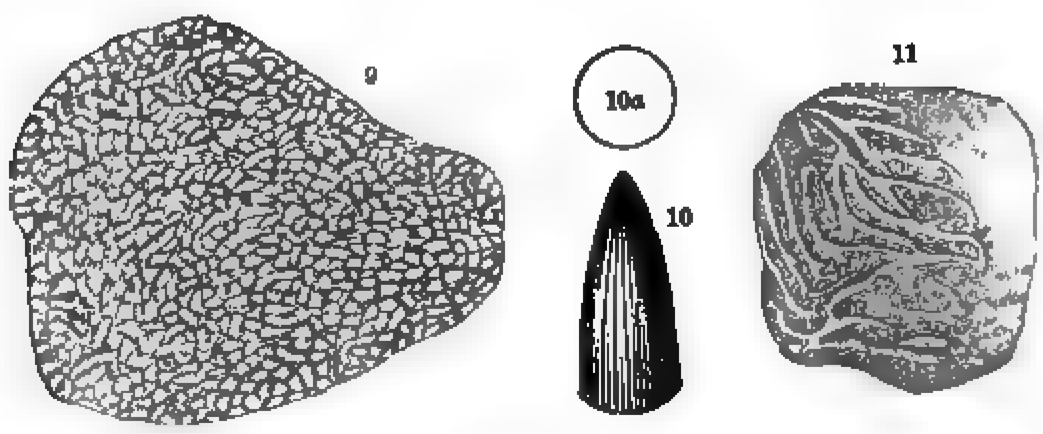


Fig. 509, Holoptychius Americanus. 510, Tooth, id.; 510 *a*, section of same tooth; 511, Holoptychius Taylori.

2. *Animals.*—Among animals, no Corals, Crinoids, Brachiopods, or Trilobites, are yet known. There are some Conchifers, such as (fig. 508) the *Modiola angusta*

(*Cypricardia angusta* Con.), and a few other species, and a *Euomphalus*; these, with fragments of fishes, make up about all that is yet known respecting the animal fossils of the beds. Among the fishes there are (fig. 509) *Holoptychius Americanus* (510 being a tooth of the same, and 510 *a*, a section of the latter); 511, *Holoptychius Taylori*. The latter species was of large size, a portion of one of the fins found in New York indicating a length of more than a foot for the entire fin.

III. General Observations.

Geography.—The location of the Catskill beds in eastern New York instead of central or western (like the Hamilton and Chemung), and their thickness there, show that a great geographical change preceded the opening of the period. The Appalachian subsidence, instead of extending north over central New York, involved the Hudson River valley, far to the eastward; and the amount of subsidence both here and in Pennsylvania and Virginia was much greater than in the preceding periods. The change, moreover, was attended with a complete destruction of all pre-existing life,—more complete than occurred in any other part of the Devonian age. Whether the Interior Continental basin was an area of dry land or of water, is not clearly apparent. The most probable supposition is that the great sinking of the border region of the continent was attended with a rising of western New York and the interior, and that the extermination of life was thus produced. In this event the Devonian age ended. After this, New York State, excepting a border on the south, lay to the north of the region undergoing progress through new formations; for the greater part of it was probably part of the dry land of the growing continent. The rocks of the Coal age, with the small exception alluded to, do not spread over it. Some geologists would make the Devonian age close with the Chemung period; but the fossil fishes of the Catskill beds, according to Dr. Newberry, appear to represent closely those of the British Old Red Sandstone or Devonian, and no similar species have been found in the Burlington or other Subcarboniferous limestones of the West.

If the view presented be correct, there is a bold transition from the closing period of the Devonian age to the opening of the Carboniferous. The former was a period in which the great Appalachian subsidence (as in other parts of the Devonian) reached north into the State of New York, while in the latter it hardly passed the limits of Pennsylvania. The former was characterized by dry land over the great Interior Continental basin; the latter, by a wide-spread, and clear though not deep, sea, growing Crinoids and forming limestones; for the Subcarboniferous limestone forma-

tions are among the most extensive in the geological series, and crinoidal remains are in great profusion.

FOREIGN DEVONIAN.

I. Rocks: kinds and subdivisions.

The Devonian rocks occur as surface-strata in most of the countries of Europe, and in parts of all the other continents.

In the British Isles, they are exposed to view in southern Wales and the adjoining county of Herefordshire; in the peninsula of Devonshire and Cornwall; along the southern flank of the Grampians, and on the northwestern side of Lammermuir from Dunbar to the coast of Ayrshire, in the valley of the Tweed, and elsewhere, in Scotland; and also in Ireland and the Isle of Man.

On the map, fig. 605, the Devonian areas are distinguished by vertical lines.

The strata in England and Scotland have long gone by the name of the Old Red Sandstone,—red sandstone being the prevailing rock in Wales and Herefordshire as well as Scotland. With the sandstone, there are beds of marl or argillaceous shale, and some limestone.

The beds of Wales are argillaceous shales or marls, of red and other colors, with some whitish sandstone and impure limestone, overlaid by red sandstone which passes above into a conglomerate; and the whole thickness is estimated by Murchison at 8000 or 10,000 feet. The limestone is concretionary, and is called *Cornstone*.

In Scotland there are, according to Hugh Miller, the following subdivisions:—

3. Upper.
   - 3. Yellow sandstone; containing *Holoptychius*, etc.
   - 2. Concretionary limestone.
   - 1. Red sandstone and conglomerate.

2. Middle—Gray sandstones and shales; containing *Cephalaspis*, etc.

1. Lower.
   - 3. Red and variegated sandstone.
   - 2. Bituminous schists; containing *Dipterus*, *Pterichthys*, *Coccosteus*, etc.
   - 1. Conglomerate and red sandstone.

In Devonshire and Cornwall the strata are of very different character. They are stated by Sedgwick as follow:—

4. Petherwin group.
   - 2. Petherwin slate and Clymenia limestone.
   - 1. Marwood sandstones.

3. Dartmouth group.
   - Roofing-slates and quartz, with variegated sandstones above, in north Devon.

2. Plymouth group.
   - 3. Red sandstone and flagstone.
   - 2. Calcareous slates.
   - 1. Great Devon limestone.

1. Liskeard or Ashburton group.

In the Eifel (Rhenish provinces) there are, below, slates and sandstones; next, the great Eifel limestone, the equivalent, apparently, of the Upper Helderberg; and above this, slates with an intermediate limestone,—the whole termed the *Cypridina slates.*

In Russia, the Devonian formation is exposed over a great extent of country. The rocks are mostly marls and sandstones with laminated limestones. According to Kutorga, the prevailing order is marls below, then sandstones, then argillaceous limestone.

There is thus a great diversity in mineral character, and no conformity in the subdivisions of the Devonian with those in America. As already explained, these subdivisions are in general due to causes that have acted too locally to be often alike and synchronous in very distant regions.

II. Life.

Plants.—Europe and Britain have afforded, in addition to seaweeds, remains of plants related in genera to those of the Coal period; so that from an early period of the Devonian the land of other continents besides America had its Ferns and Conifers. The earliest fossil Conifer in Britain was found by Hugh Miller in his lower division of the Old Red Sandstone of Scotland.

In Goeppert's recent memoir on the plants of the Silurian, Devonian, and Lower Carboniferous rocks, he gives 20 Silurian species, all *Algæ*; in the Lower Devonian, 5 *Algæ* and 1 *Sigillaria*; in the Middle Devonian, 1 *Sagenaria*; in the Upper Devonian, 57 species, all but 7 land-plants.

Animals.—The range of animal life was similar to that of America. A few species of Europe and America were identical; but the great majority were distinct, showing that the continents did not derive their life from one another. But as regards genera the identity was very nearly complete. The continents were marching on with nearly equal step in the progress of life.

Corals were abundant in Europe, especially Favosites and the Cyathophylloid species, and coral-reefs were forming in the Eifel and some other parts. Mollusks were most abundantly represented by *Brachiopods*, and Crustaceans by *Trilobites* and the little *Ostracoids*. Among Brachiopods, *Spirifers* were very common, and the genus *Productus* made its first appearance, along with others of less prominence. *Goniatites* also (a genus of Cephalopods) was a new type, and became well represented before the close of the age.

The sub-kingdom of Vertebrates included numerous fishes,—some that were several feet long: they were all either *Selachians* or *Ganoids*. A few are represented, of reduced size, in figs. 516–519. With so powerful species in the water, it is not a matter of surprise

that the clumsy Orthocerata of the Silurian age were succeeded by fewer and smaller species.

Just before the Devonian age closed, there were *Reptiles* in the world. This is a second step in the unfolding of the Vertebrate type. The skeleton of one small species, called *Telerpeton*, is represented in fig. 520. Moreover, besides these remains, tracks of *Amphibians* have been observed, proving that air-breathing animals frequented the marshes.

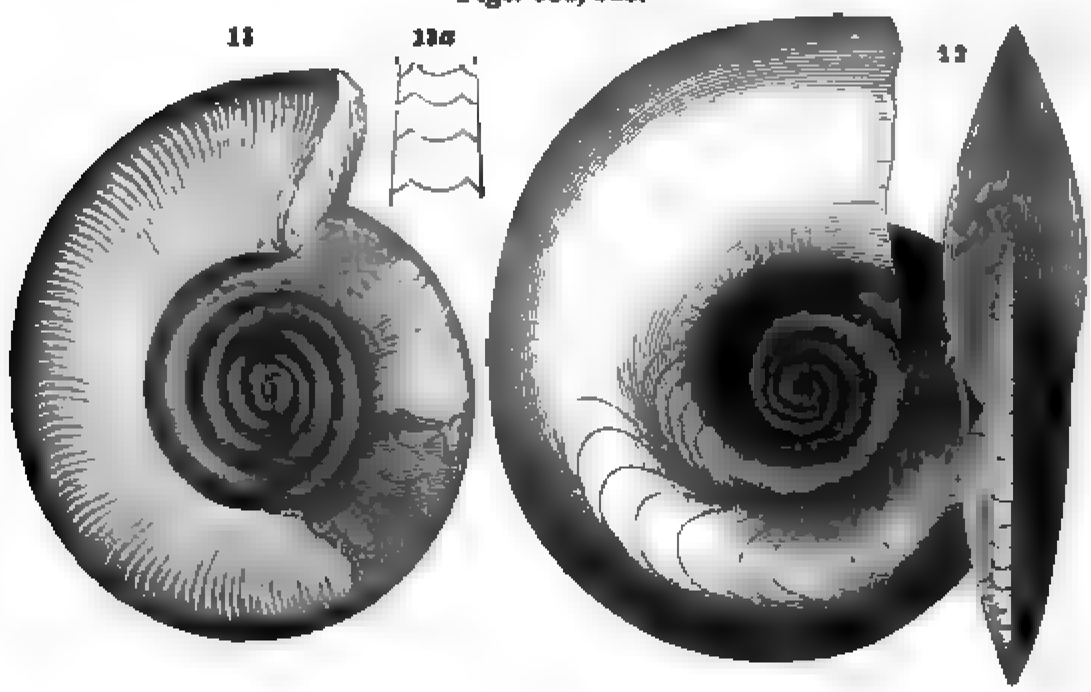
Characteristic Species.

1. **Radiates.**—Among Radiates there were species of *Pentremites*, the earliest in Europe of the group of Blastoid Crinoids.

2. **Mollusks.**—*Brachiopods* included species of *Orthis*, *Strophomena*, *Atrypa*, *Rhynchonella*, *Spirifer*, *Productus*, *Chonetes*, etc.; besides *Calceola* and *Stringocephalus*, which are confined to the Devonian age. Fig. 231 is the *Calceola sandalina* (so called from the sandal-like shape of the shell). This genus characterizes the *Calceola schist* which underlies the great Devonian limestone of the Eifel.

Conchifers were numerous of the genera *Avicula*, *Aviculopecten*, *Pterinea*, *Nucula*, *Conocardium*; also of *Arca*, *Grammysia*, *Megalodon*, etc. There were *Gasteropods* (all without beaks) of the old genera *Murchisonia*, *Euomphalus*, *Pleurotomaria*, *Loxonema*, *Bellerophon*, etc. There were others also of the new genus *Porcellia*, which is near Bellerophon, and somewhat resembles an Ammonite in form, but has a deep dorsal slit in the aperture of the shell.

Figs. 512, 513.



Cephalopods.—Fig. 512, Goniatites retrorsus; 513, Clymenia Sedgwickii; 513 a, dorsal view of septa.

Cephalopods include a few species of the Orthoceras family,—also *Nautili*, and several species of the new genus *Goniatites*, of the Ammonite family, and of

another, called *Clymenia*. Fig. 512, *Goniatites retrorsus*; fig. 513, *Clymenia Sedgwickii*. The shell in *Clymenia* has the form in the Ammonites, but, unlike the Goniatites and Ammonites, the siphuncle is ventral instead of dorsal, and the septa have no distinct dorsal lobe on the medial line, as shown in fig. 513 *a*.

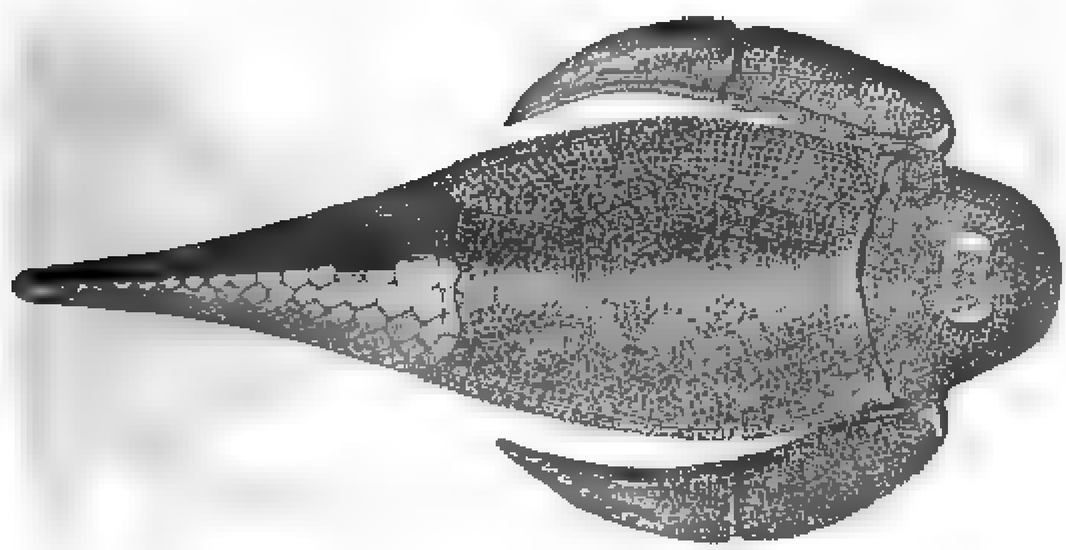
3. **Articulates.**—There are a number of species of Trilobites, though less than in the Silurian: the genus *Phacops* or *Dalmania* is most common. *Homalonotus* has European species, and one, *H. armatus*, has spines on the head and two rows along the back. This spinous feature reaches its maximum in the Devonian *Arges armatus* (fig. 514).

Figs. 514, 515.

CRUSTACEANS.—Fig. 514, Arges armatus; 515, Slate containing Cypridina serrato-striata, natural size; 515 *a*, same, enlarged.

Minute Ostracoids, referred to the genus *Cypridina*, abound in the *Cypridina slate*, giving this name to the beds. Fig. 515 represents a portion of the slate or

Fig. 516.



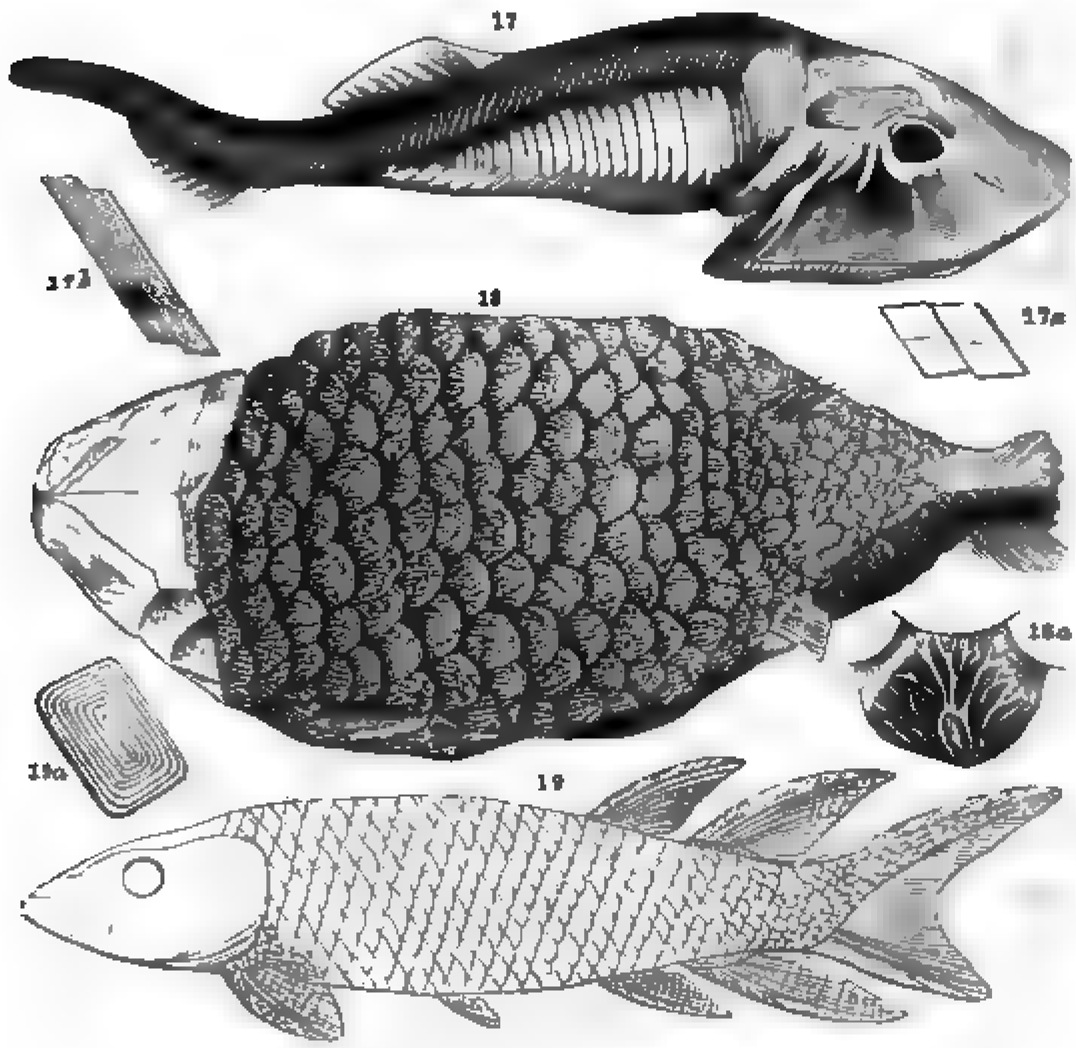
Pterichthys Milleri.

shale with the shells of the *Cypridina serrato-striata* on its surface, natural size, and 515 *a* is one of the shells, enlarged.

4. Vertebrates.—In the Devonian rocks of Great Britain and Europe, a large number of species of fishes have been found; and when we consider how little likely fishes are to become buried and fossilised, we begin to appreciate their vast abundance in the Age of Fishes.

Among *Ganoids*, fig. 516 represents the Placoderm *Pterichthys Milleri* (as restored by Pander), reduced to half the natural size. The *Coccosteus* resembles it in its plates, but has a longer tail, fitted for sculling by means of a fin along the upper and under sides. Fig. 517, the *Rhombifer* Ganoid *Cephalaspis Lyellii;* figs. 517 *a*, 517 *b*, scales of the same; fig. 518, the *Imbricate* Ganoid *Holoptychius*; fig. 518 *a*, scale, id.; fig. 519, another Rhombifer, *Dipterus macrolepidotus.*

Figs. 517–519.



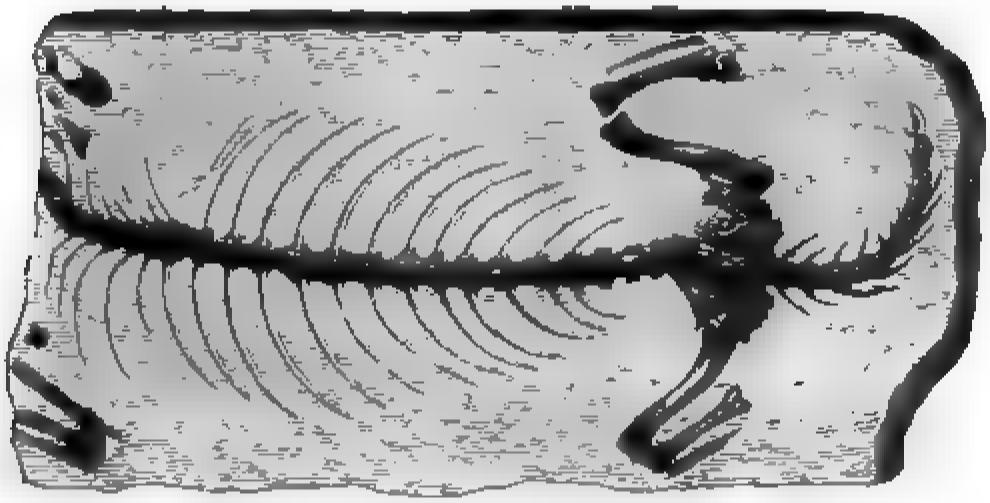
GANOIDS.—Fig. 517, Cephalaspis Lyellii; 517 *a*, *b*, Scales, id., 518, Holoptychius; 518 *a*, Scale, id.; 519, Dipterus macrolepidotus; 519 *a*, Scale, id.

Asterolepis Asmusi Agassiz, whose remains occur both in Russia and Scotland, must have been 20 to 30 feet long.

Reptiles.—Fig. 520, *Telerpeton Elginense* Mantell, a species found on the south side of the Moray Firth, in a whitish sandstone rock which is regarded by most

geologists as Devonian, though suspected to be Triassic. The animal appears to have been more Lacertian than Batrachian; and this superiority to other

Fig. 520.



Telerpeton Elginense.

species of the next period is partly the occasion of the doubt as to its being true Devonian. In the same quarry there have been observed thirty-four consecutive footprints of a four-footed animal which was probably amphibian. The tracks of the fore-feet are one inch broad, and those of the hind-feet three-fourths of an inch, while the stride was four inches.

GENERAL OBSERVATIONS ON THE DEVONIAN AGE.

American Geography.—1. *General features.*—The facts gathered from the Silurian strata lead us to conceive of the age—far the longest of all the ages, excepting the Azoic—as one of small, barren lands in the midst of great waters. We may suspect the existence of land-plants; yet the suspicion is not sustained by observation. But before the Devonian age had half passed, the land had become covered with vegetation, preparatory for a freer and nobler life than that of the waters. Still, the dry land of the continents had increased but little in extent. The Azoic area, which had been enlarged on the north by successive additions from emergence during the Silurian, had expanded farther in the same direction, until, at the close of the Devonian, the State of New York formed a part of the land that bore the new vegetation. For, as seen on the map, p. 170, the rocks which succeed one another reach less and less far northward, proving that there was this progress southward with each period.

The general map on page 133 shows the area over which the Silurian and Devonian formations are now uncovered in other parts

of the United States. But we cannot conclude that no later rocks ever existed over these areas; for extensive strata may have been washed away in the course of subsequent changes. Yet there had been progress in the dry land from the north, southward, along the region of Ohio and Wisconsin, as in the State of New York, and also from the Azoic axis of the far north, westward and eastward: so that a general expansion of the old Azoic had taken place, by additions to all of its borders. South of New York, and over a large part of the continent, the surface was still liable to alternate sinking and rising, and was, therefore, open to new formations. North America was in the main a continental sea, with the extent of land that was permanently dry very limited as compared with the present finished continent.

In place of the Rocky Mountains and Appalachians, there were only islands, reefs, and shallow waters, to mark their future site; for Carboniferous strata and others of later age cover the slopes of the Western mountains even over their summit-plains, and a limestone of the Carboniferous age has been observed in one place at a height of 13,000 feet above the sea. The fossils of these rocks are the remains of animals that lived in the continental seas of that region in the next age after the Devonian. The Appalachians also contain in their structure rocks of the Devonian and Carboniferous eras. The Green Mountains have been already spoken of as in part dry land; but, as rocks of the Devonian and Carboniferous seas constitute portions of New England, they could not have had their present elevation, and were probably low.

It follows, from the limited area of the land and the absence of high mountains, that there were no large rivers at the time. With the close of the Devonian the Hudson River may have existed with nearly its present limits, and in Canada the Ottawa and other streams drained the northern Azoic. Even the St. Lawrence above Montreal may have been a fresh-water stream.

2. *Rocks of marine and not of fresh-water origin.*—None of the strata bear evident marks of fresh-water origin. The shale deposits and mud-rocks, which have been described, are such as might have been formed by fresh waters; but they all contain fossils, few or many, which are of the same genera and often the same species with those of beds obviously marine. Proofs of fresh-water depositions, therefore, still fail us. Their absence may be accounted for on the grounds—(1) that there were no great rivers; (2) that whatever material was borne to the sea was worked up by the waves and filled with marine life; and (3) that depositions over the land, excepting perhaps in those parts of the continent that were perma-

nently dry, would have been arranged anew by the waves in times of submergence.

3. *Geographical changes.*—The history of the periods of the Devonian has been shown to be, like that of the Silurian periods, a history of successive oscillations in the continental level,—the position of the accumulating deposits varying more to the east or to the west with the varying location of the subsiding or emerging areas. Throughout the whole, the Appalachian region continued to be well defined. Its deposits consisted mainly of shales and sandstones, and they have a total thickness of not less than 15,000 feet; while in the West the rocks are for the most part limestones, with a thickness of less than 500 feet.

It appears, moreover, that in the Devonian as well as Silurian age, the interior region was covered with but thin beds of any kind,—thin sandstones when sandstones were formed, and thin limestones compared with the cotemporaneous shales and sandstone strata farther east; and hence the oscillations of level there indicated are small as compared with those of the Appalachian region. Moreover, from the prevalence of limestone strata in the West we learn that the great mediterranean sea of the Silurian age was continued far into the Devonian, opening south into the Atlantic and Gulf of Mexico, and reaching north probably to the Arctic. Through some parts of the West, the Niagara and Upper Helderberg limestones—the formations of that interior sea—follow each other with but little interruption.

European Geography.—The European continent in the Devonian age could not have had the simplicity of features and movement that characterized the American. It is obvious from the great diversity of the Devonian rocks—sandstones at one end of Britain and limestones at the other, limestones in the Eifel on the Rhine and almost none in Bohemia—that the continent had not its one uniform interior sea like North America, but was an archipelago, diversified in its movements and progress.

There may have been proportionally more elevated heights over the area; but it is still true that there was little of it dry; that the loftier mountains had not been made,—the Alps and Pyrenees being hardly yet in embryo; and that, with small lands and small mountains, rivers must have been small. No fresh-water deposits have yet been distinguished; the salt ocean was nearly universal. Within it, animals were living, and the continent was forming at shallow depths.

Life.—The introduction of *land-plants* and that of *fishes* are the two great steps of progress that especially mark the Devonian age.

The *land-plants* belong to two prominent groups,—*Conifers* and *Acrogens* (p. 166). The former are the lowest of flowering plants, the latter the highest of the flowerless plants, or Cryptogams. Mosses, an inferior group of Cryptogams, are unrepresented. Thus the new creations commenced with neither the highest nor the lowest of plants, but at an intermediate point in the series, where the lower and higher groups come together. There was neither moss nor grass; and no showy flowers existed to contrast with the verdure. The Conifers have inconspicuous flowers, and of all flowering plants approximate most nearly in fructification to the Acrogens. Moreover, between the Acrogens and the Conifers of the era there was an intermediate group (although most closely related to the latter), which included the Sigillariæ: so that there was a remarkable unity in the early botany of the world. The Acrogens represented belong to the Lycopodium, Equisetum, and Fern tribes.

The *Fishes* of the age are also of two groups,—the *Selachians*, or Sharks, and the *Ganoids*. The earliest species, therefore, instead of being the lowest of fishes, belong to the highest of the three grand divisions: moreover, instead of being small, some of them were twenty or thirty feet long. The Selachians are highest among fishes even in modern seas.

These early fishes—especially the Ganoids—have strong Reptilian characteristics, as Agassiz long since observed, and they were thus *comprehensive* types, foreshadowing the class of Reptiles afterwards created. Hence, while plants began at the middle of the scale, Fishes commenced at the top,—not, indeed, with the very highest tribes of the groups introduced, for these belong to later time; but the groups themselves rank highest in the class of Fishes, as stated. In fact, the commencement was at a point above the true level of Fishes, verging towards the higher grade of Reptiles; and it was not till long afterwards that the fish-type appeared in its purity.

Among Ganoids, the species of *Pterichthys* (fig. 516) have many of the characters of a turtle,—its paddles and its covering of plates; and those of *Coccosteus* present features of some sculling reptiles. Many of the other Ganoids are Sauroid, in having the teeth closely like those of the early Reptiles, and a joint made of concave and convex surfaces at the junction of the head and neck, hence admitting of some motion,—a characteristic belonging to none of the common osseous fishes (Teliosts). Another Reptilian characteristic is the lung-like structure of the air-bladder, the organ which answers to the lung in air-breathing Vertebrates. Moreover, the old Ganoids bear two striking marks of antiquity: (1) they have cartilaginous skeletons, and (2) vertebrated tails. Besides, they are at the present

time nearly an extinct tribe. With a rare exception, the vertebrate character of the tail does not recur after the Palæozoic.

The further history of the type of Fishes is a subject of special interest, as will appear in the sequel.

Besides land-plants and fishes, reptiles are supposed to date from the last epoch of the Devonian,—though the evidence is not beyond suspicion, as stated on p. 299. If correct, the beds may still be synchronous with those called Lower Carboniferous in Pennsylvania, in which similar tracks have been observed; and in this case the discrepancy between the facts thus far ascertained on the two continents is slight. Remarks on the Reptilian remains are therefore deferred to a following page, under the Carboniferous.

The progress of life during the Devonian is further seen in—

(*a.*) The introduction of many new genera under old tribes; for example, *Productus* among Brachiopods, which began in America in the Corniferous period, and had its maximum display, and also its extinction, in the Carboniferous age: *Goniatites* among Cephalopods, which had its earliest American species in the Hamilton period, and became extinct at the same time with Productus,—a genus of interest, as it is the first of a family (that of Ammonites) which had a wonderful extension under other genera in the Reptilian age, and became extinct to its very last species at the close of that age; *Nucleocrinus* (fig. 452), the earliest (after a single Lower Silurian genus) of the *Pentremites*, another of the eminently Carboniferous types; the ellipsoidal form of Nucleocrinus is changed to the pentagonal of Pentremites (fig. 531) with the first of the Subcarboniferous species, or even before, in the Upper Devonian.

(*b.*) The complete or approximate extinction of tribes: as that of the *Cystids*, which ended with the Oriskany period in America and the epoch of the Eifel limestone in Europe; that of *Favistella*, *Heliolites*, and other genera of Corals and Crinoids; that of *Atrypa*, *Calceola*, *Stringocephalus*, and other genera of Brachiopods; that of the Chain-coral, or *Halysites*, which does not appear above the Upper Silurian in America, but is found in the Eifel limestone in Europe; that of *Trilobites*, which, after there had been, under a succession of genera, over 600 species, came nearly to its end in the Devonian, the old genera being all extinct, and only three new ones appearing in the Carboniferous, to close off this prominent Palæozoic type; the *Orthoceras* family, species of which are comparatively rare fossils after the Devonian age.

(*c.*) In the historical changes in tribes or genera: for example, the *Spirifers*, which began in narrow species in the Upper Silurian, become broad-winged and very numerous in the Devonian, and

continue thus into the Carboniferous; the genus *Productus*, whose earliest species are very small and few, are afterwards of large size and numerous. These changes do not consist in the gradual variation of the earlier species; for species are essentially constant in their characteristics. They become apparent solely in the succession of species,—the later species created differing in the particulars mentioned from those which preceded them.

Each of these points admits of extensive illustration; but the above is sufficient to give an idea of the kind of progress life was undergoing. Each period had its new creations and its extinctions, and often, also, there were many successive creations and extinctions in a single period. Families and tribes were in constant change; and through all these changes the system of life was in course of development.

Threads running through past time to the present era increased very slowly in number; for to the genus *Lingula*, which, if correctly determined, reaches to the farthest distinguishable limit in the history of animal life, with *Nautilus*, *Rhynchonella*, *Crania*, and *Discina*, of the Silurian, only *Nucula*, *Terebratula*, and perhaps *Arca*, are added in the course of the Devonian age. These genera are all Molluscan. Every other (exclusive of some comprising the inferior organisms called Rhizopods, see p. 163) becomes extinct before the Age of Man. The early life was thus cast off, as the earth became adapted to new forms in the expanding system.

DISTURBANCES CLOSING THE DEVONIAN AGE.

In eastern Canada, Nova Scotia, and Maine, the Devonian and Silurian strata are uplifted at various angles beneath unconformable beds of the Carboniferous (Dawson, Logan, C. Hitchcock). These uplifts preceded the Carboniferous age (or at least the Carboniferous period); but the precise epoch of their production—that is, whether before the close of the Devonian age, or not, or whether partly in the Silurian—is yet to be ascertained. Those in Maine, according to Hitchcock, probably took place at the close of the Devonian; and the same may be true of the others alluded to.

In Iowa, Wisconsin, and Illinois, there are also similar uplifts; but the Lower Carboniferous strata are involved in the disturbance, and these, with the subjacent beds, lie unconformably beneath the Coal formation. Here, therefore, the uplifts must have taken place partly at least (perhaps wholly) *after* the period of the Lower Carboniferous.

In England and Bohemia, also, examples of disturbances between the Devonian and Carboniferous have been observed.

But all these cases are small exceptions to the general fact that the Lower Carboniferous and the underlying rocks are conformable almost the whole world over. The epoch of transition was not an epoch of general disturbance. There were extensive oscillations of level, but in general they involved no violent upturnings. The Carboniferous age opens with a period of marine formations, and the beds accumulated, in most regions where they occur, as a regularly-continued series.

CARBONIFEROUS AGE.

This age is divided into three periods:—

I. The SUBCARBONIFEROUS PERIOD (13).
II. The CARBONIFEROUS PERIOD (14).
III. The PERMIAN PERIOD (15).

The Carboniferous age, both in America and Europe, commenced with a preparatory marine period,—the SUBCARBONIFEROUS; had its consummation in a long era of extensive continents, covered with forests and marsh-vegetation, and subject at long intervals to inundations of fresh or marine waters,—the CARBONIFEROUS; and declined through a succeeding period,—the PERMIAN, in which the marsh-vegetation became less extensive, and the sea again prevailed over portions of the Carboniferous continents.

American Geographical Distribution.

The rocks of the Carboniferous age lie at the surface over large areas of North America. (See map, p. 133, in which the black areas and those cross-lined or dotted on a black ground are of this age.)

A. *In the United States:*

1. Over parts of Rhode Island and Massachusetts, between Newport and Worcester.

2. Along the Appalachian region from New York into Alabama, and spreading west over half of Ohio, and part of Kentucky and Tennessee, and a little of Mississippi.

3. Over central Michigan.

4. Over much of Illinois, and spreading eastward over part of Indiana, southward over part of Kentucky, westward over part of Iowa, Minnesota, Missouri, Kansas, Arkansas, and large portions of the Rocky Mountain slopes.

5. In Texas.

6. About the summits of the Rocky Mountains, near several of the passes; around the Great Salt Basin in Utah; in the Colorado basin, New Mexico, and over some other parts of the Pacific slope of the Rocky Mountains.

7. In northern California.

B. *In the British Provinces:*

1. Over much of New Brunswick and part of Nova Scotia.

2. In the Arctic, over Melville and other islands between Grinnell Land and Banks Land.

The Coal measures cover a large part of most of the regions here pointed out, the rest being occupied by the Subcarboniferous and Permian, or by limestones and other barren beds of the Carboniferous period.

Excepting the areas west of the Rocky Mountains, the whole pertain to three great regions or basins:—

I. The *Interior Continental region*, including the Appalachian area on the east, and stretching west to western Kansas, and perhaps still farther, to or beyond the summit of the Rocky Mountains; for Carboniferous rocks probably underlie the later beds now at the surface. It is divided into two parts by the Lower Silurian uplift about Cincinnati and the region southwest.

II. The *Atlantic border region*, including the New Brunswick and Nova Scotia region, and that of Rhode Island,—also divided into two parts, a northern and southern.

III. The *Arctic region*.

1. SUBCARBONIFEROUS PERIOD (13).

I. Rocks: kinds and subdivisions.

In the *Interior Continental region* the Subcarboniferous rocks are mainly limestones. They are largely displayed in Illinois, Kentucky, Iowa, and Missouri, and in the last they have a thickness of 1200 feet. They also occur in Arkansas and Texas. In Tennessee there are two groups: the *lower*, siliceous beds; the *upper*, limestone. In Michigan there are about 70 feet of limestone, resting upon 480 feet of shales and sandstones. The great limestone of the Carboniferous age over parts of the slopes and sum-

mits of the Rocky Mountains is regarded as belonging mainly to the Carboniferous period, and not to the Subcarboniferous.

In the *Appalachian region* of Pennsylvania, the rocks are sandstones and shales, and are divided into two groups. The *Lower* consists mainly of sandstones, and is thickest and most varied in composition in the vicinity of the southeastern anthracite coal region, in which, at Pottsville, the thickness is 1800 to 2000 feet. It diminishes rapidly in thickness to the west. The *Upper* is composed mostly of shales. It attains its maximum thickness in the same region as the Lower, being 3000 feet thick on the Lehigh, at Mauch Chunk. It thins out to the northward, and becomes somewhat calcareous to the southwest. (Rogers.) In Virginia the shales become still more calcareous, and a great formation of Subcarboniferous limestone commences which extends into Alabama.

Going westward from Pennsylvania into Ohio, the fragmental deposits diminish in thickness, and become reduced to a comparatively thin group of arenaceous beds.

There are thin workable seams of *coal* in some of these Subcarboniferous beds of Pennsylvania and Virginia, and also valuable beds of *clay iron-ore.*

(*a.*) *Interior Continental basin.*—The Subcarboniferous limestone of the Mississippi valley—especially in Illinois and Iowa—is divided, according to Hall, into five distinct groups, each having its characteristic fossils:—

1. The Burlington limestone (500 feet thick in Missouri), overlaid in Iowa by cherty beds (60 to 100 feet).
2. The Keokuk limestone (40 or 50 feet at Keokuk).
3. The Warsaw limestone (50 to 100 feet).
4. The St. Louis limestone (250 feet thick), overlaid by ferruginous sandstone (200 feet).
5. The Kaskaskia limestone.

The Burlington limestone is made up to a considerable extent of Crinoidal remains, and has afforded many fine species. The Warsaw limestone is sometimes called the *Lower Archimedes limestone*, from the species of *Archimedes*, which is common in it near Warsaw and elsewhere. The Keokuk and Warsaw limestones are not separated in Missouri by Swallow, who makes the united thickness in some places 200 feet: he names the whole the Archimedes limestone. The St. Louis limestone is partly a brecciated rock, but generally a light-gray, fine-grained limestone, and is remarkable for the fine species of *Melonites* (fig. 536), and also the coral *Lithostrotion Canadense* (figs. 521, 522). The Kaskaskia limestone has been styled the *Upper Archimedes limestone*: it contains many Crinids, especially of the genera *Poteriocrinus*, *Zeacrinus*, and *Scaphiocrinus* (Hall). The Burlington limestone extends two hundred miles farther north in the Mississippi valley than the succeeding limestones.

To the south, in Kentucky and Tennessee, the subdivisions of these limestones disappear, and cannot be well made out even by the fossils.

In Illinois, the Burlington limestone is underlaid by the "Kinderhook Group," also Subcarboniferous, consisting of sandstone and shale with some local beds of limestone, the whole about 100 feet thick. (Worthen.) In Missouri, the *Chouteau* and *Lithographic limestones* are regarded by some as equivalents of this inferior group of the Subcarboniferous, rather than of the Upper Devonian to which they have been referred.

In Tennessee, the lower Subcarboniferous beds are siliceous, as already mentioned. In *eastern* Tennessee (which borders on the Appalachian region), this *lower* or *Siliceous Group* consists of shales and sandstones many hundred feet thick; in *middle* Tennessee, it is a siliceous rock 200 to 300 feet thick, more or less calcareous, with some cherty layers, especially to the south, and also intercalated beds of Crinoidal limestone. These siliceous beds reach south into Alabama. The *upper* group in Tennessee, though mainly limestone, has in some parts near its middle a band of sandstone 50 to 100 feet thick.

The Michigan Carboniferous area appears to have been an independent basin at the time of the formation of the rocks. There are four groups of strata, according to Winchell: the first, or lower, 171 feet of grits and sandstones, which he has called the *Marshall Group*; the second, 123 feet of shales and sandstones, called the *Napoleon Group*; the third, 184 feet of shales and marl, with some limestone and gypsum, called the *Michigan Salt-group*; the fourth, the Carboniferous limestone, 66 feet thick. This limestone is well exposed at Grand Rapids.

In Ohio, the "Waverly sandstone," usually referred to the Upper Devonian, has been referred in part at least to the Subcarboniferous, and it probably corresponds in horizon with the "Marshall Group" of Michigan and the "Kinderhook Group" of Illinois. According to this conclusion, there is at the base of the Subcarboniferous a series of fragmental rocks over a very wide region.

A Subcarboniferous limestone occurs near Lake Utah, in lat. 40° 13′ N., long. 112° 8′ W., containing the characteristic *Archimedes*. It is an exception to the general fact that the limestone of this age in the Rocky Mountains belongs to the second or Carboniferous period.

(*b.*) *Appalachian region.*—The rocks of the *lower* group in the Appalachian region directly overlie the Devonian and Catskill beds, and are, in the main, coarse grayish conglomerates and sandstones; those of the *upper* group are soft shales mostly of a red color.

The *lower* group has its greatest thickness in Pennsylvania and Virginia, being 2000 feet thick near Pottsville. Through much of the anthracite coal basin it constitutes the encircling hills, as around the Wyoming basin, and in many places forms a grayish-white band over another of red, the latter due to the Catskill beds,—the two thus making a red and white frame, as Lesley says, around the valleys or basins. It thins rapidly to the westward; the rock retains its whitish color and siliceous character in Virginia. Sandstone beds alternate with the conglomerate; and in New York these finer layers abound in ripple-marks, and that oblique lamination (fig. 61 *e*) which is due to contrary currents.

The shales of the *upper* group are soft, reddish, clayey beds, easily returning, on exposure, to mud, the original condition of the material. They alternate with sandstone layers, especially in the lower part. At Towanda, Blossburg, Ralston, Lockhaven, Portage Summit, etc., in upper Pennsylvania, the formation consists of two or three thick strata of shale separated by as many strata, 50 to

200 feet thick, of greenish sandstone. (Lesley.) Some thin layers consist of an impure, rough-looking limestone.

This red-shale formation is 3000 feet thick at the Lehigh, Schuylkill, and Susquehanna Rivers; but on crossing the Coal measures to the westward it rapidly diminishes. At Broad Top it is less than 1000 feet; at the Alleghany Mountain, hardly 200; at Blairsville, 30 feet; and beyond, it is lost to view. (Lesley.)

The soft shales retain still the ripple-marks from the ancient waves, and raindrop impressions from the showers of the day. The amphibian footprints described beyond are from this formation.

Seams of coal occur in the Subcarboniferous at many places in Pennsylvania and Virginia. In Montgomery co., Va., there is a layer of coal, two to two and a half feet thick, resting on a bed of conglomerate; and 30 to 40 feet higher there is another layer, six to nine feet thick, consisting of alternations of coal and slate. These coal beds occur in the *Lower* group, and are covered by the shales of the Upper. In Pennsylvania, there is a coal bed (and possibly two) in the same *Lower* group at Tipton, at the head of the Juniata, 600 feet below the *Upper* shales: but, as far as known, it is a local deposit (Lesley). The Subcarboniferous coal deposits are sometimes called *false coal measures*.

(c.) *Eastern border region.*—In Nova Scotia, the Subcarboniferous rocks are red sandstones and red and green marls, with thick limestones full of fossils. The estimated thickness is 6000 feet. To the north, towards the Azoic, the limestones fail, and, instead, the rocks are to a greater extent a coarse conglomerate. To the south, limestones prevail. Beds of gypsum accompany the limestones. The localities of these beds, mentioned by Dawson, are the Carboniferous districts of northern Cumberland, Pictou, Colchester and Hants, Richmond county and southern Inverness, Victoria, and Cape Breton.

In the lower part of these Subcarboniferous beds, as in those of Virginia, there are, on a small scale, *false coal measures*, and in one instance a bed of *erect trees*, under-clays, and thin coal seams; and the same beds contain numerous remains of fish.

The fish-bearing shales of Albert Mine, New Brunswick, are referred to this period by Dawson, from whom the above facts are cited. This mine affords a peculiar pitch-like or *asphaltic coal*, which has been regarded by some investigators as a true coal seam much altered in the course of the violent folding and metamorphic changes to which the rocks of the region, as all admit, have been subjected; and by others as an inspissated mineral oil filling a fissure in the beds. The coal is mentioned on p. 68, and analyses are given on the following page.

In Pennsylvania, *two epochs* may be distinguished in the Subcarboniferous,—namely, the *Alleghany*, corresponding to the *lower* beds, and the *Schuylkill*, corresponding to the *upper* beds. It is probable that the two divisions in Tennessee (p. 308) are equivalents of these, and that the Alleghany epoch corresponds to the lower of the Western Subcarboniferous limestones, the Burlington and Keokuk, with the underlying beds.

II. Life.

1. *Plants.*

The land-vegetation of the Subcarboniferous period was very similar to that of the Lower Carboniferous, and descriptions of species are therefore not given in this place. It may have been as profuse for the amount of land, although the circumstances were less favorable for its growth and accumulation in marshes,—the essential prerequisite for the formation of large beds of coal.

2. *Animals.*

The animal life was remarkable for the great profusion and diversity of Crinoids,—or Sea-lilies, as they are sometimes called. Some of the Crinoids—mutilated of their rays or arms, as is usual with these fragile species—are represented in figs. 523–535. The period might well be called the Crinoidal period in geological history. Among the kinds, the *Pentremites* (figs. 530–532) are perhaps the most characteristic. Instead of having a circle of arms, like most Crinoids, the summit is closed up so as to look like a bud (whence the name Blastoidea, applied to the family, from the Greek *βλαστος, a bud*), and the delicate jointed tentacles are arranged along the pseudo-ambulacral areas in vertical lines.

Among Corals, the auger-shaped Retepores called *Archimedes* are characteristic. (See fig. 537.) They are properly Molluscan of the tribe of Bryozoans. A true Polyp-Coral, eminently characteristic of the period, is the *Lithostrotion Canadense* (figs. 521, 522). It is a columnar coral, having a conical elevation at the bottom of each of the cells, and grows often to a very large size.

Besides these, Brachiopods were numerous, especially of the genera *Spirifer* and *Productus*. There were also many Cephalopods of the genera *Goniatites* and *Nautilus*, and but few of the *Orthoceras* family. Trilobites were rare; Selachian and Ganoid fishes very abundant.

While the limestones of the West abound in fossils, the shales and sandstones of the Appalachian region have afforded few of any kind, and those mainly Conchifers and Gasteropods.

The most interesting are the tracks of an amphibian reptile,—*Sauropus primævus* Lea, the earliest American species known. Some of the tracks from near Pottsville, Pa., are represented on fig. 549. There is a succession of six steps along a surface little over five feet long: each step is a double one, as the hind-feet tread nearly in the impressions of the fore-feet. The print of the

fore-feet is something like that of a hand with five stout fingers, the whole four inches broad; that of the hind-foot is similar, but somewhat smaller, and four-fingered. The reptile was therefore large; this is also evident from the length of the stride, which was thirteen inches, and the breadth between the outer edges of the footprints, eight inches. There is also a distinct impression of a tail an inch or more wide. The slab is crossed by a few distant ripple-marks (eight or nine inches apart), which are partially obliterated by the tread. The whole surface, including the footprints, is covered throughout with rain-drop impressions.

We thus learn that there existed in the region about Pottsville, at that time, a mud-flat on the border of a body of water; that the flat had been swept by wavelets leaving ripple-marks; that the ripples were still fresh when a large amphibian walked across the place; that a brief shower of rain followed, dotting with its drops the half-dried mud; that the waters again flowed over the flat, making new deposits of detritus, and so buried the records.

Characteristic Species.

1. **Protozoans.**—Although the class of *Rhizopods* probably commenced in the lowest Silurian, the earliest described species from an American rock is the *Rotalia Baileyi* Hall, from the Carboniferous limestone of Indiana.

Sponges.—The hornstone of the Subcarboniferous limestones of Illinois abounds in microscopic spicula of sponges, along with a few Desmids similar in general to those of the Corniferous limestone (p. 271). (M. C. White.)

2. **Radiates.**—(*a*.) *Polyps.*—Figs. 521, 522, *Lithostrotion Canadense* Castelnau (*L. mamillare* of some authors,—among whom Milne Edwards, after thus naming it, makes a correction in a note), from the St. Louis limestone.

Fig. 521.

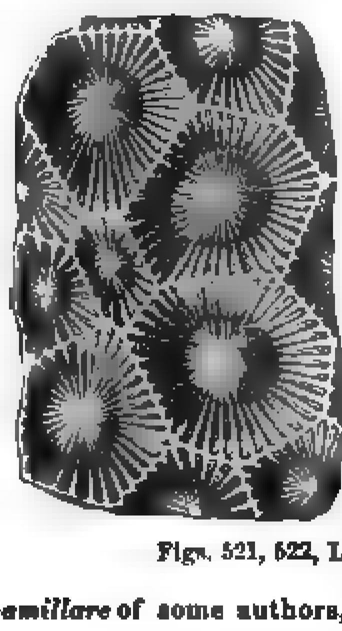
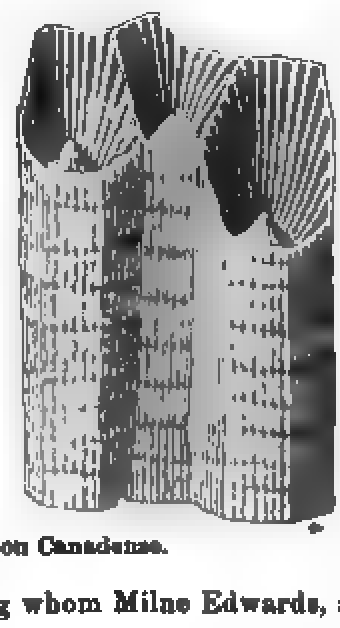


Fig. 522.



Figs. 521, 522, Lithostrotion Canadense.

(*b.*) *Echinoderms: Crinoids.*—Fig. 530, *Pentremites pyriformis* Say; figs. 531, 532, *P. Godonii* De France (*P. florealis*, in part),—both from the Kaskaskia limestone; fig. 523, *Poteriocrinus Missouriensis* Shumard, from the St. Louis lime-

Figs. 523–535.

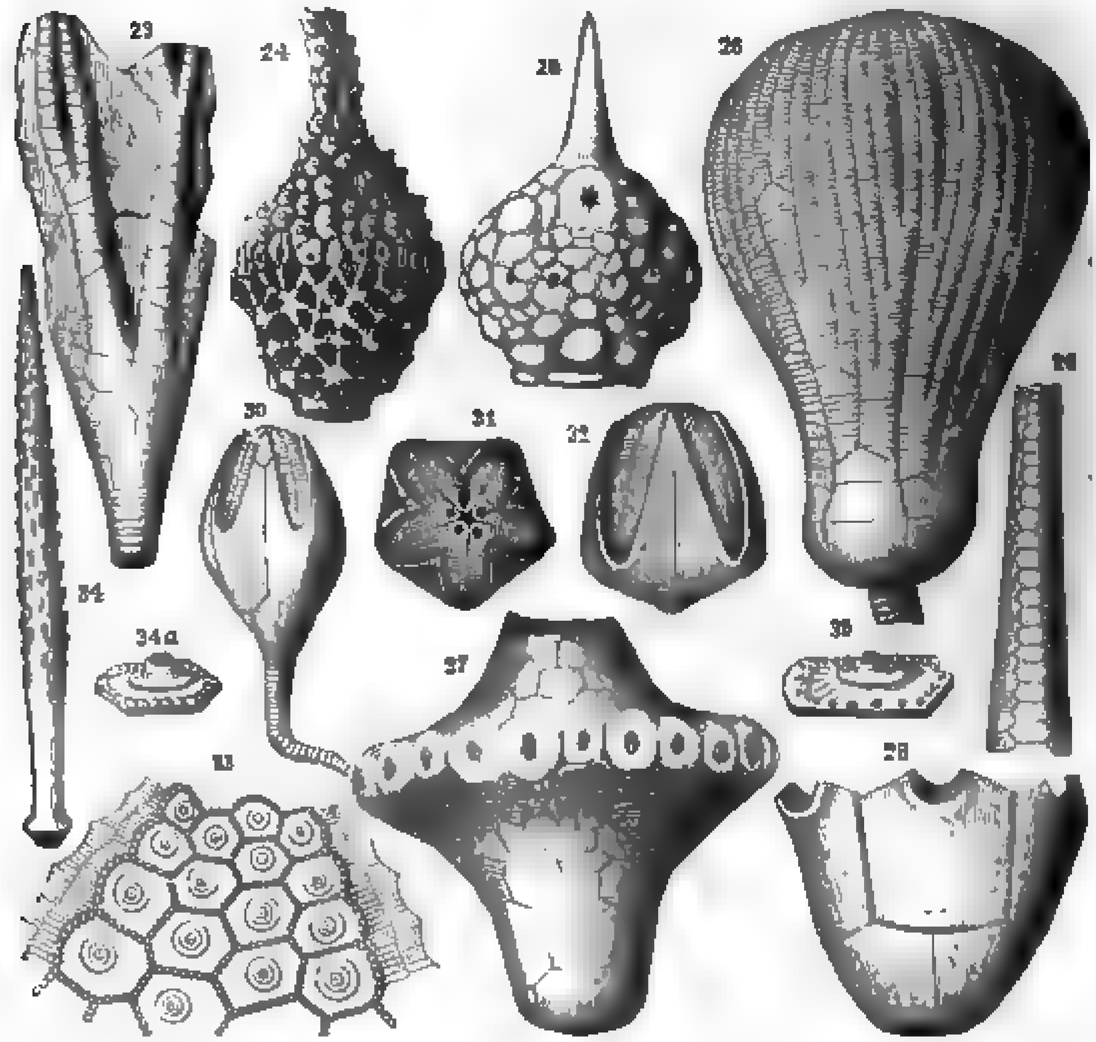


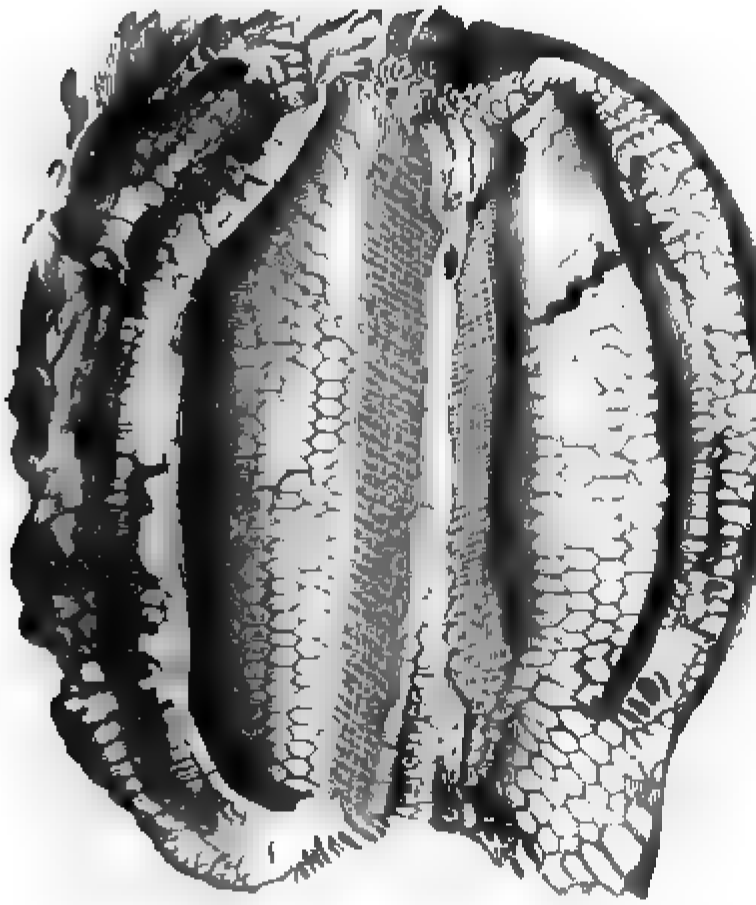
Fig. 523, Poteriocrinus Missouriensis; 524, Actinocrinus proboscidialis; 525, A. unicornis; 526, Zeacrinus elegans; 527, Actinocrinus Christyi; 528, Platycrinus Saffordi; 529, the proboscis of Actinocrinus longirostris; 530, Pentremites pyriformis; 531, 532, P. Godonii (florealis); 533, Archæocidaris Wortheni; 534, 534 *a*, A. Shumardana; 535, A. Norwoodi.

stone; fig. 524, *Actinocrinus proboscidialis* H.; fig. 525, *A. unicornis* Owen & Shumard; fig. 526, *Zeacrinus elegans* H.,—this and the two preceding from the Burlington limestone; fig. 527, *Actinocrinus Christyi* Shumard, the arms fallen off,—from the Encrinal limestone of Missouri; fig. 529, proboscis of *Actinocrinus longirostris* H.; fig. 528, *Platycrinus Saffordi* Troost, side-view, from Burlington. Most of the above Crinoids have lost their arms and pedicels.

Echinoids.—Fig. 533, *Archæocidaris Wortheni* H., of the St. Louis limestone; fig. 534, *A. Shumardana* H., of the Warsaw limestone,—a spine,

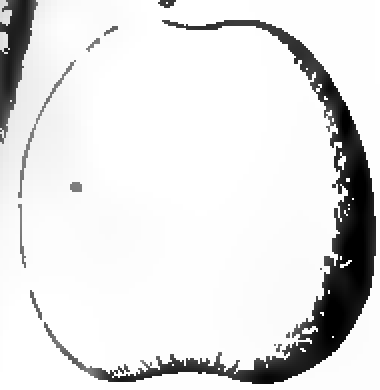
enlarged; fig. 534 *a*, a plate of the same species, enlarged about two diameters; fig. 535, a plate of *Archæocidaris Norwoodi* H., natural size, from

Fig. 536.



Palæchinus (Melonites) multipora (×½).

Fig. 536 *a*.



Outline view of the restored Melonites.

the Kaskaskia limestone; fig. 536, *Melonites multipora*, from the St. Louis limestone, half natural size, but crushed; 536 *a*, an outline, showing the form of the unbroken shell. The genus *Archæocidaris*, like the modern Cidaris, has large prominences on the plates to support the spines, which are also large. In *Melonites* and *Palæchinus* the plates are without prominences, and the spines were small. The *Pentremites* above mentioned occur through nearly all the limestone or upper group in Tennessee.

Fig. 537.

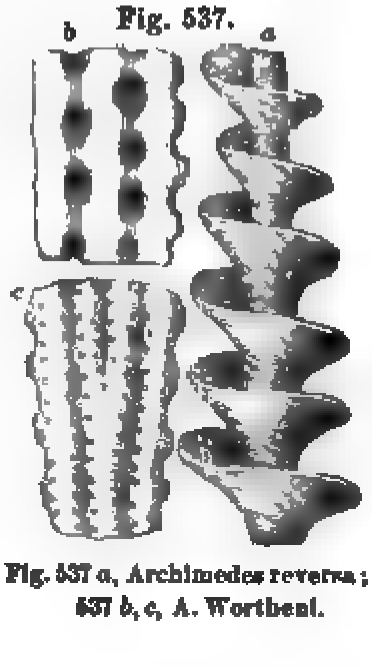


Fig. 537 *a*, Archimedes reversa; 537 *b*, *c*, A. Wortheni.

3. **Mollusks.**—(*a*.) *Bryozoans.*—Fig. 537 *a*, *Archimedes reversa*, being a portion of the spiral axis with the reticulated expansion removed. Fig. 537 *b*, a portion of the reticulated expansion of *A. Wortheni*, magnified and showing the non-poriferous surface. Fig. 537 *c*, the poriferous side of the same.

(*b*.) *Brachiopods.*—Fig. 538, *Chonetes ornata* Shumard (nat. size), from the Lithographic and Chouteau limestones, Missouri; 538 *a*, enlarged sur-

face-markings of same; fig. 539, *Spirifer biplicatus* H., from Burlington and Quincy, Illinois; fig. 540, *Orthis Michelini* (var. Burlingtonensis H.), from the Burlington limestone; *Orthis* (*Streptorhynchus*) *Umbraculum* (fig. 550); fig. 541, *Spirifer octoplicatus*; fig. 542, *Sp. bisulcatus* (*increbescens* H.); fig. 543, *Retzia Vernenilana* H.; fig. 544, *Chonetes variolata* A. d'Orbigny; fig. 544 *a*, hinge-line of same, and aperture closed by a pseudo-deltidium; fig. 545, *Productus punctatus* Martin; also *P. Flemingii* Sowerby, *P. elegans* Norwood & Pratten, *Spirifer incrassatus* Eichwald, *Sp. spinosus* Norwood & Pratten, from the Kaskaskia limestone, etc. The *Spirifer incrassatus* is confined in Missouri to the lower Archimedes limestone. Most of the other Brachiopods occur not only in the Subcarboniferous beds, but also in the Carboniferous. They are common also in Europe.

Figs. 538, 539.

Figs. 538, 538 *a*, Chonetes ornata; 539, Spirifer biplicatus.

Figs. 540–545.

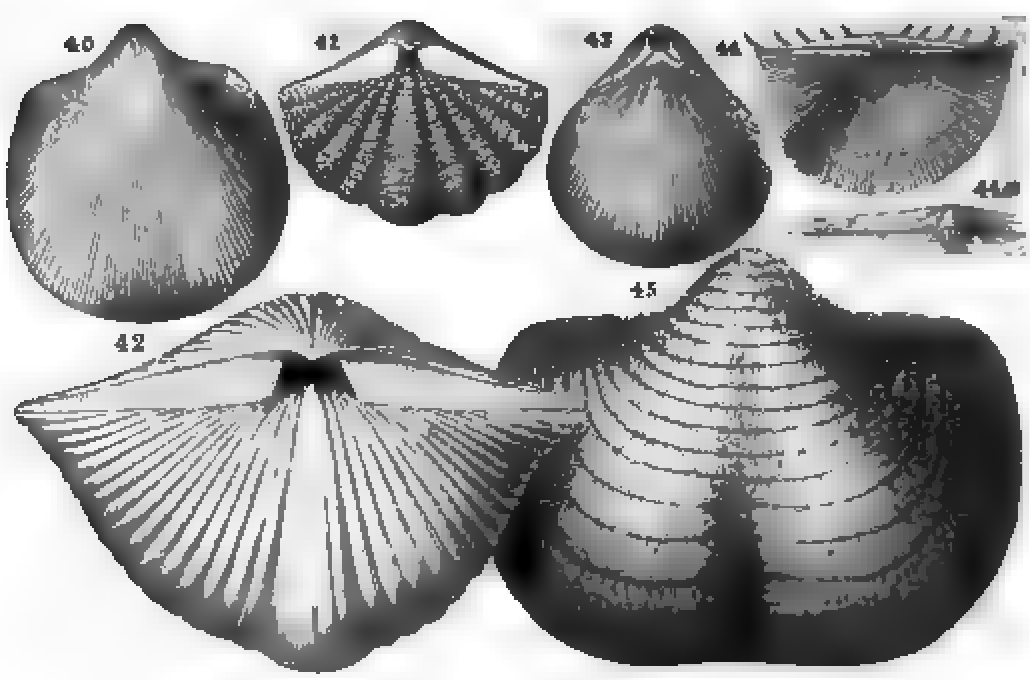


Fig. 540, Orthis Michelini, var Burlingtonensis, 541, Spirifer octoplicatus; 542, Sp. bisulcatus; 543, Retzia Verneuilana; 544, 544 *a*, Chonetes variolata; 545, Productus punctatus.

There are also Gasteropods of the genera *Platyceras*, *Straparollus*, *Naticopsis*, *Pleurotomaria*, *Machrocheilus*, *Loxonema*, etc. The Cephalopods are of the genera *Nautilus*, *Orthoceras*, *Gyroceras* (the *Gyroceras Burlingtonensis*, from Burlington, Iowa, five inches in diameter), *Goniatites*, etc.

4. **Articulates.**—A few Trilobites of the genus *Phillipsia*.

5. **Vertebrates.**—*Fishes* of the Selachian genera *Cochliodus*, *Cladodus*, *Orodus*, *Carcharopsis* (*Pristicladodus*), etc., besides others of the order of Ganoids. Fig. 546 is a tooth (natural size) of *Cochliodus nobilis*, from Illinois. This fish is

one of the Cestraciont sharks, and must have been of great size, far exceeding those reported from Europe. The corresponding plates of the *C. contortus* are given in fig. 547, reduced to one-third natural size. Fig. 548 A, *Cladodus spinosus*

Fig. 546.

Fig. 547.

Fig. 546, Cochliodus nobilis; 547, C. contortus (× ⅓).

Newberry & Worthen, from the St. Louis limestone, Missouri; *a*, section of the same; fig. 548 B, *Carcharopsis Wortheni* Newberry, from Huntsville, Ala.; fig. 548 C, *Orodus mamillaris* N. & W., from the Warsaw limestone, Warsaw, Ill.

Fig. 548.

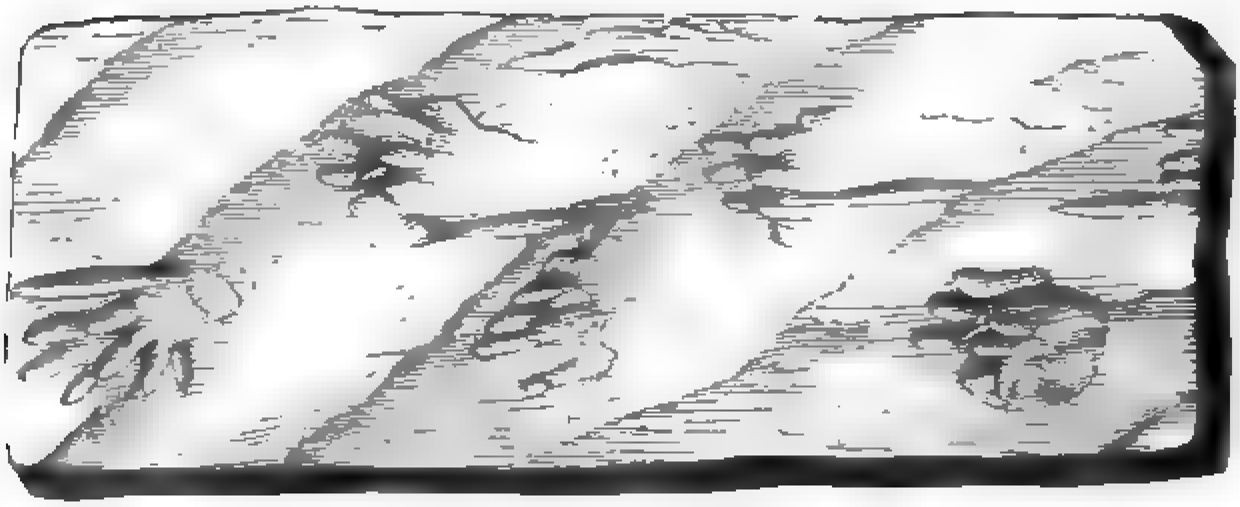
Fig. 548 A, Cladodus spinosus; 548 B, Carcharopsis Wortheni; 548 C, Orodus mamillaris.

Reptiles.—Fig. 549. Tracks of *Sauropus primævus*, one-eighth natural size, discovered near Pottsville, Pa., by Isaac Lea, who has published a memoir upon them in very large folio, with a magnificent full-size engraving of the slab with the footprints.

The Carboniferous limestones of Nova Scotia and New Brunswick con-

tain some fossils that ally the Fauna more with the European than with that of the Interior Continental basin of North America. Among them are

Fig. 549.



Tracks of Sauropus primævus (× ⅙).

the *Spirifer glaber* (fig. 554) and *Productus Martini*, both of which are European species.

III. General Observations.

Geography.—As in the first half of the Upper Silurian there was a period—the Niagara—when a sea profuse in life, and thereby making limestones, covered a large part of the Interior Continental basin; and again in the early part of the Devonian age—the Upper Helderberg period—the same conditions were repeated; so in the early Carboniferous there was a similar clear and open mediterranean sea, and limestones were forming from the relics of its abundant population. In the period of the Upper Silurian referred to, the living species were of a miscellaneous character, Brachiopods, Crinoids, and Corals occurring in nearly equal proportions; but in that of the Devonian, Corals were greatly predominant, and in that of the Carboniferous, Crinoids had as remarkable a pre-eminence. By an open sea is meant one having free connection in some part with the ocean; and this connection must have been on the south, towards the Mexican Gulf; for the arenaceous deposits of the wide Appalachian region show that there was not, probably, a direct opening eastward into the Atlantic. The mediterranean sea alluded to was, in fact, only an extension northward of the Mexican Gulf.

These interior waters in the Subcarboniferous period had narrowed limits on the east: for they no longer spread over New York,

and probably they hardly passed the western boundary of Ohio. The Silurian area stretching southwestward from Cincinnati, mentioned on a former page (p. 228), may have been a barrier between the eastern and western waters. The absence of the limestone from that region and from among the Subcarboniferous strata in eastern Ohio (where it seems replaced by sandstone) affords strong evidence that the elevation about Cincinnati had previously taken place. To the north in Michigan and south in Tennessee, the earlier beds were shales and sandstones,—the former State being near the northern border, and the latter in proximity to the Appalachian region. In Michigan the strata are *Saliferous*, and the conditions of the Salina period of the Upper Silurian in New York (p. 249) were probably there repeated. Over both of these districts circumstances were afterwards changed—probably through a progressing subsidence—from those favoring sedimentary accumulations to those characterizing the clear Crinoidal sea. But at the same time that sinking was going on in these parts, a rising of the sea-bottom appears to have taken place to the northwestward in Iowa, as Hall has observed; since after the formation of the Burlington limestone, the succeeding limestone in the series has its northern limit 200 miles more to the southward, and the others still farther south, indicating a contraction of the sea from that direction. The greatest thickness of these limestones, moreover, is in Missouri, where it amounts to 900 feet, or, with the intercalated arenaceous beds, to 1200 feet.

It may be again repeated, that no great depth of water was required for the Crinoidal sea.

The Appalachian region, as in past time, was one of extensive accumulations of conglomerates, sandstones, and shales. Nearly 6000 feet of rock—five times the greatest amount in the West—were formed in the course of the period. The thickness of the formations, both in the East and West, is an approximate measure of the amount of subsidence in each. In its more southern part (from Virginia southward), however, there were limestones in progress as in the interior sea.

The Eastern border region is a repetition in many points, though on a smaller scale, of the more western portion of the continent. The resemblance of the fossils to the European, according to Dawson, implies a more direct connection through the Atlantic with the eastern continent than existed between Europe and the Interior basin.

FOREIGN SUBCARBONIFEROUS.

The Subcarboniferous period was a time of limestone-making also in Britain and Europe. There is proof, therefore, of a wide extension of those geographical conditions that characterized America,—that is, of an extensive submergence of the continental lands, as a prelude to the period of emergence and terrestrial vegetation that followed.

The limestone is often called the "mountain limestone." It occurs in southern England and Wales, over large areas in Russia, in Germany, Belgium, France, Spain, etc. In Ireland the thickness is stated as varying between 1200 and 6400 feet. In the Hartz there are slates and sandstones of the same age.

Life.

Plants.—Small coal-seams and many species of coal-plants occur in the strata. The plants are related to those of the lower Coal measures, and are, for the most part, the same in species. In some places, as in northern Scotland, the rocks of the Subcarboniferous and Carboniferous periods so run together, by the intercalations of limestones with the latter, that they have not yet been well distinguished. The plants are further considered under the Carboniferous period.

Animals.—The "mountain limestone," like the American beds, is noted for its Crinoids; its Brachiopods of the genera *Productus* and *Spirifer;* its Corals of the genus *Lithostrotion;* its Ganoid Fishes and Sharks; its few Reptilian relics; and also for the absence of Trilobites of all the old genera.

Characteristic Species.

The following are a few of its characteristic species. Fig. 550, *Streptorhynchus* (formerly *Orthis*) *Umbraculum* (common in the American Carboniferous); fig. 551,

Figs. 550–552.

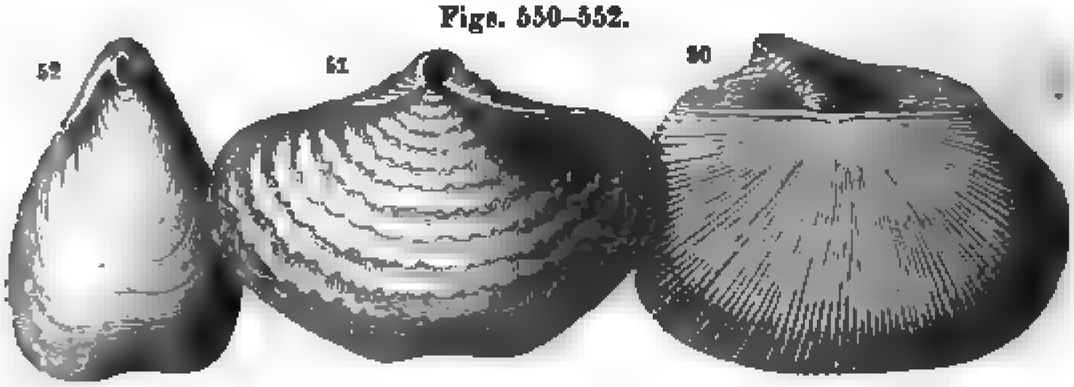


Fig. 550, Streptorhynchus Umbraculum; 551, Athyris lamellosa; 552, Terebratula hastata.

Athyris (*Spirigera*) *lamellosa;* fig. 552, *Terebratula hastata;* fig. 553, *Productus*

longispinus; fig. 554, *Spirifer glaber*. *Spirifer speciosus* and *Chonetes Dalmaniana* are common species. *Pleurotomaria carinata* retains its original colored markings, as first observed by the late Professor Forbes; and this author hence inferred that

Figs. 553–555.

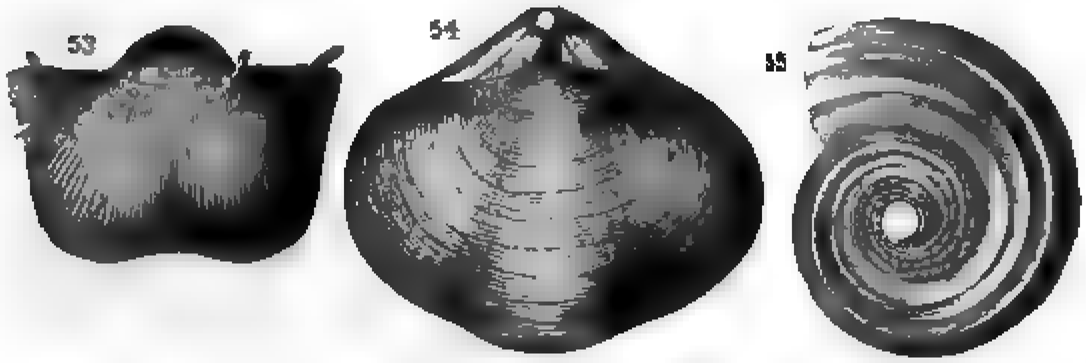
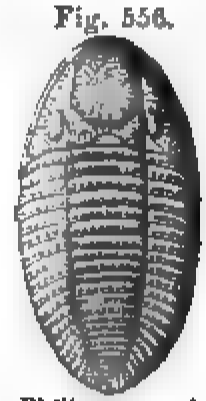


Fig. 553, Productus longispinus; 554, Spirifer glaber; 555, Nautilus (Trematodiscus) Koninckii.

it was a shallow-water species, as only such have shells figured with colors. Fig. 555, *Nautilus* (*Trematodiscus*) *Koninckii*.

Trilobites occur of the only three Carboniferous genera, *Phillipsia*, *Griffithides*, and *Brachymetopus*. Fig. 556 is *Phillipsia seminifera*.

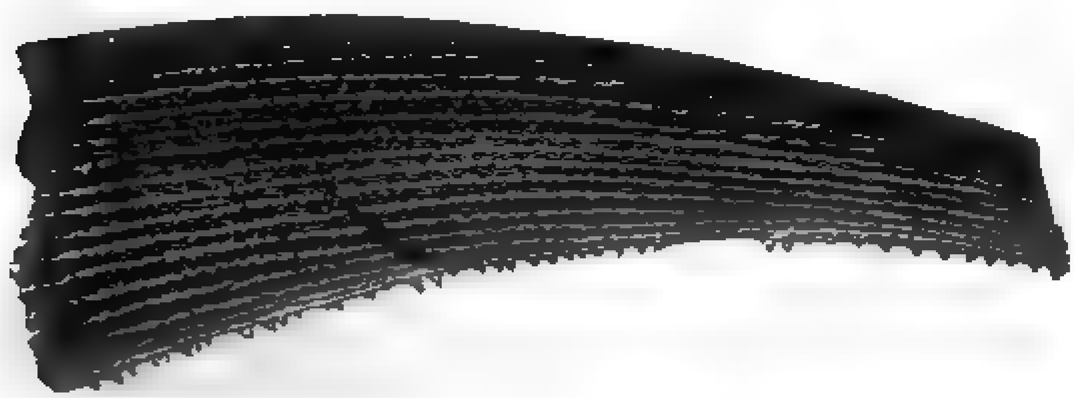
Fig. 556.



Phillipsia seminifera.

Remains of fishes are very common in Europe and Britain. Among Cestracionts (or sharks with pavement-teeth) there are *Cochliodus contortus* (fig. 547); among Hybodonts (or sharks with regular teeth, the teeth with obtuse or rounded edges) there is the *Cladodus marginatus*. Fig. 557 represents a small specimen of one of the great fish-spines of this period, called *Ctenacanthus major* by Agassiz. One specimen has a length of *fourteen and a half inches*, and was probably eighteen inches in the living Cestraciont. The old fishes, as Agassiz observes, must have had gigantic dimensions, if we may judge from the size of the spines.

Fig. 557.



Part of a spine of Ctenacanthus major.

Another spine, *Oracanthus Milleri*, Agassiz, is nine and a half inches long and three inches wide at base, and yet it has lost some inches at its extremities. These

specimens, and numerous other remains of fishes, are found in a fish-bone bed in the mountain limestone at Bristol, England, and also in the same rock at Armagh, Ireland. The British and European species, although numerous and often large, do not exceed in either respect those which have been already found in connection with the Subcarboniferous beds of the United States.

DISTURBANCES PRECEDING THE CARBONIFEROUS PERIOD.

It was remarked on page 305 that the Devonian beds are very generally conformable with the Subcarboniferous, and therefore afford in but few places indications of uplifts before the Subcarboniferous period and its formations began. There is the same conformability for the most part between the Carboniferous and Subcarboniferous; yet the examples of the absence of it are more numerous, and cover some wide regions. Through the investigations of Norwood, Daniels, Foster, and Hall, it is now known that the Coal measures of Iowa, Missouri, and Illinois rest unconformably upon the strata beneath, and Hall observes "that this is so whether these strata be the Subcarboniferous, Devonian, Upper Silurian, or Lower Silurian." The want of conformability is very distinct in certain parts, and but slight in others; and in some cases it is apparent only in the marks of extensive surface-denudation which took place at some time preceding the Coal period.

In the annexed sections, the coal beds rest on tilted Silurian strata. Fig. 558 is a section in northern Illinois. The Coal measures here overlie the Lower Silurian; *a*, calciferous sandrock; *b*,

Fig. 558.

St. Peter's sandstone (Chazy?); *c*, Trenton and Galena limestone; *d*, Coal measures. (J. W. Foster.) Fig. 558 A was taken at Port Biron, Rock Island co., Illinois, and shows the Coal measures A, resting unconformably on the Niagara limestone B. (Worthen.) In this region, the strike of the uplift is parallel to the course of the Rocky Mountains, or nearly northwest. A portion of

Fig. 558 A.

these uplifts directly preceded the Coal period. But others may be of earlier date; for where the tilted rocks underneath are Silurian or Devonian instead of Subcarboniferous, it is not yet certain

[illegible] preceded the Carboniferous age. More [illegible] fix the date.

[illegible] New Brunswick.

In Great Britain, Russia, and the most of Europe, [illegible] rous and Subcarboniferous beds, when occurring together, [illegible] formable. But in central and southern France [illegible] the two are clearly unconformable. In Bavaria [illegible] carboniferous limestones and Devonian [illegible] though inclined together at a large angle [illegible] Bohemia lie in horizontal strata over their tilted [illegible]

2. CARBONIFEROUS PERIOD [illegible]

Epochs.—1. Epoch of the Millstone grit; 2. Epoch of the Coal measures.

1. EPOCH OF THE MILLSTONE GRIT [illegible]

I. Rocks: kinds and distribution.

The Carboniferous period opened with a marked change over the continent. The Subcarboniferous limestones and [illegible] which were formed upon the submerged land became covered with extensive gravel or pebble beds, or deposits of sand; the beds of that epoch, hardened into a gritty rock, make up the millstone grit and sandstone which underlie the Coal measures.

Similar conglomerates and sandstones were formed afterwards in the course of the Coal measures; but this rock is prominent for its extent, and for marking the commencement of the Coal era.

The Coal period in Britain has in general the same kind of introduction: the term *Millstone grit* applied to the rock comes to us from England.

This Millstone grit extends over parts of some of the southern counties of New York, with a thickness of 25 to 60 feet; and, owing to the regularity of the joints, it stands out in huge blocks, walls, and square structures, that have suggested such names as "Rock City" and "Ruined City" (Cattaraugus and Allegany cos.). It occurs through all the Coal areas of Pennsylvania, both the eastern and western; it is from 1000 to 1500 feet thick about the centre of the anthracite region, and diminishes rapidly to the westward. It stretches southwestward through Virginia to Alabama.

West of the Appalachian region, the rock is in part a pebbly sandstone, but often only a fine-grained, arenaceous rock; and from some portions of the Mississippi basin it is absent.

Thin beds of coal occur in these conglomerates, and in certain localities they are of workable extent.

(*a.*) *Interior Continental basin.*—In Ohio, Indiana, and Illinois, there are 40 to 100 feet of pebbly sandstone; in eastern Kentucky, a sandstone, which is 50 feet thick on the Ohio and 250 on the borders of Tennessee; in western Kentucky, a conglomerate, called the Caseyville conglomerate. It is probable that these conglomerates and sandstones, referred to the beginning of the Coal measures, belong to this initial epoch of the period. In Arkansas, the *novaculite* used extensively for hones, and also great numbers of quartz crystals, occur in beds referred to this epoch.

(*b.*) *Appalachian region.*—The grit in Pennsylvania is mostly a whitish siliceous conglomerate, with some sandstone layers and a few thin beds of carbonaceous shale: it overlies the Subcarboniferous shale or sandstone. At Tamaqua, the thickness is 1400 feet; at Pottsville, 1000 feet; in the Wilkesbarre region, 200 to 300 feet; at Towanda, Blossburg, etc., where it caps the mountains, it is 50 to 100 feet thick. (H. D. Rogers.)

In Virginia, the thickness is in places nearly 1000 feet: the rock is mainly a sandstone, but contains heavy beds of conglomerate. The conglomerate of the Subcarboniferous, in a similar manner, becomes an arenaceous rock in Virginia. In Alabama, the rock is a quartzose grit of great thickness: it is used for millstones.

(*c.*) *Eastern border region.*—In the Nova Scotia and New Brunswick Coal region, a millstone grit has been observed in the Carboniferous district of northern Inverness and Victoria; but only sandstones overlying gypsiferous rocks in Pictou co., and shales and sandstones at the Joggins.

2. EPOCH OF THE COAL MEASURES (14 *b*).

I. Distribution of the Coal Areas.

The Carboniferous areas of North America have been pointed out on p. 305. The regions corresponding to the Coal period (black areas on the map, p. 133) are—

1. The great *Appalachian* coal field, covering parts of Pennsylvania, Ohio, Virginia, eastern Kentucky, eastern Tennessee, and Alabama. The workable area is estimated at 60,000 square miles. The whole thickness of the formation is 2500 or 3000 feet: aggregate thickness of the included coal beds, over 120 feet in the Pottsville and Tamaqua valley, about 62 feet near Wilkesbarre, 25½ feet at Pittsburg. The area is partly broken up into patches in Pennsylvania, as shown in the following map. In the centre of the State, between Pottsville and Wyoming, are the famous anthracite beds, divided

into many distinct patches; and in the western part commences the great bituminous coal field which spreads into Ohio and stretches on south to Alabama.

2. The *Illinois and Missouri*, covering a very considerable part of Illinois, part of Indiana and Kentucky, and, west of the Mississippi, portions of Iowa, Missouri, Kansas, and Arkansas. Estimated area, 60,000 square miles. Whole thickness of the formation, in Missouri, 600 to 1000 feet; in western Kentucky, nearly 3300 feet, —with about 70 feet for the aggregate thickness of the coal beds.

Fig. 559.

Map of part of Pennsylvania, showing the Coal areas of the State, in black; also the Mesozoic red sandstone formation, *obliquely lined across.*

3. The *Michigan*, situated about the centre of the peninsula. Estimated area, about 5000 square miles. Whole thickness of the

formation, 123 feet; rests upon a sandstone, probably of the Millstone grit epoch, which is 105 feet thick.

4. The *Texas*, covering several of the northern and northwestern counties.

5. The *Rhode Island*, lying between Providence and Worcester in Massachusetts, and opened at Cumberland north of Providence, at Portsmouth 23 miles south, and also showing thin seams at Newport and elsewhere; in Massachusetts, outcropping at Mansfield 15 miles northeast of Providence, at Wrentham 5 miles from Mansfield, and at Worcester. Estimated area, 1000 square miles.

6. The *New Brunswick*, covering part of New Brunswick, Nova Scotia, Prince Edward's Island, and Newfoundland. Estimated area, 18,000 square miles. Whole thickness of the formation at the Joggins, including the beds of the Millstone-grit epoch, 14,570 feet: the number of included coal beds is 76, some of them being very thin, and the aggregate thickness 45 feet. (Logan.) These coal beds are situated in a part of the Coal measures, 2819 feet thick, near the middle of the series. At Pictou there are six beds of coal, with an aggregate thickness of 80 feet. (Dawson.)

The total number of square miles of all the productive coal fields of the United States is 125,000.

Besides the above, there is the *Arctic* Coal region, which has been observed on Melville and Bathurst Islands, Banks Land, etc., and the *Rocky Mountains*, both of which are yet unexplored.

Limestones of the Carboniferous period—formerly supposed to be Subcarboniferous—have a wide distribution over the summit and both the eastern and western slopes of the mountains. This limestone has been observed at the Black Hills in Dakota, and the Laramie Range; about the head-waters of the Missouri; at the South Pass of the Rocky Mountains; in the ranges south of Pike's Peak, and east and west of Santa Fé, New Mexico; in the great basin of the Colorado; and it probably underlies to a considerable extent the Mesozoic rocks of the Rocky Mountain slopes west of the Mississippi.

II. Rocks.

1. *Kinds of rocks, and stratification.*—The Coal measures include stratified rocks of all kinds,—sandstones, conglomerates, shales, shaly sandstones, limestones; and the limestones are generally impure, or magnesian. There is the same wide diversity that occurs in the Devonian, with more numerous and rapid transitions than were common in that age. Moreover, the rocks differ much in different regions.

The Coal beds are additional layers in the series, interstratified

with the shales, sandstones, conglomerates, and limestones. But they are thin, compared with the accumulation of rock-strata. The Coal measures contain, generally, 50 feet or more of beds of rock to *one foot* of coal.

Iron-ore beds also occur, making other thin layers in the series, and rendering the Coal regions the best iron regions of the globe.

The following section is an example of the alternations (beginning below):—

1.	Sandstone and conglomerate beds	120 feet.
2.	COAL	6 "
3.	Fine-grained shaly sandstone	50 "
4.	*Siliceous iron-ore*	1½ "
5.	Argillaceous sandstone	75 "
6.	COAL, upper 4 feet shale, with fossil plants, and below a thin clayey layer	7 "
7.	Sandstone	80 "
8.	*Iron-Ore*	1 "
9.	Argillaceous shale	80 "
10.	LIMESTONE (oolitic), containing *Producti, Crinoids*, etc	11 "
11.	*Iron-Ore*, with many fossil shells	3 "
12.	Coarse sandstone, containing trunks of trees	25 "
13.	COAL, lying on 1 foot slaty shale with fossil plants	5 "
14.	Coarse sandstone	12 "

The alternations are thus various, and may follow any order. The shales, sandstones, conglomerates, and limestones resemble the corresponding rocks of other periods, and *they are distinguished as belonging to the Coal measures only by the fossil plants or animal relics they may contain.* Disastrous errors are often made when this rule is not regarded.

The beds, even when thick, whether of coal or of any of the rocks mentioned, have in some districts a limited lateral extent; yet in this respect the Coal measures differ little from earlier formations. Some of the larger beds of coal are supposed to spread continuously over many thousand square miles of area.

In connection with the Coal measures of Rhode Island there are extensive beds of quartzose conglomerate, which outcrop at Newport and elsewhere, and form a bold feature in the landscape at "Purgatory," 2½ miles east of Newport. They occur also in Massachusetts, between this region and Boston, showing well about Roxbury. The exact position of the beds in the series is not known, as the rocks have undergone great disturbance, and in some places so much metamorphism that the cementing material is a talcose schist. At Taunton, Mass., its pebbles have occasionally been found to contain Lingulæ of the Potsdam sandstone (*Lingula prima*), proving that they are pebbles of this Primordial rock; but whence derived is unknown.

Besides the rocks mentioned, a buhrstone occurs in beds several feet thick, in Ohio. It is a cellular, flinty, siliceous rock, valued highly for millstones.

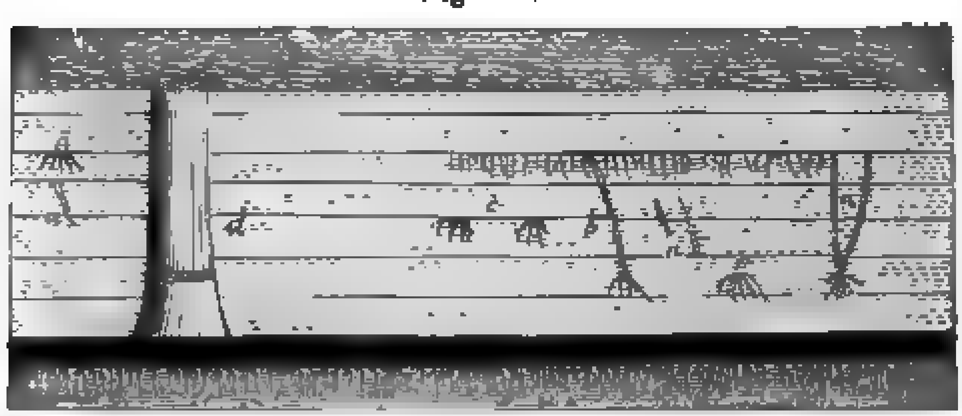
The limestones are more extensive in the Coal measures of the Mississippi basin than in those of Pennsylvania and Virginia; while, on the contrary, conglomerates are much less common in the West. This accords with the fact, learned from the earlier ages, that the Appalachian region is noted for its conglomerates and sandstones, and the Interior basin for limestones.

In Wayne co., in western Pennsylvania, there are 30 feet of limestone in 350 feet of Coal measures; and near Wheeling, on the Ohio, twice this thickness of limestone. In Missouri, there are 150 feet or more of the former to 650 of the latter. In the lower 150 feet of the Missouri section there are, however, but 8 feet of limestone, and in 900 feet of the Lower Carboniferous in western Kentucky, only 10 feet. The limestones included among the strata appear often to have a limited lateral range, instead of the uniformity over extended areas common in earlier periods.

The rock underlying a coal bed may be of either of the kinds mentioned; but usually it is a clayey layer (or bed of finer clay) which is called the *under-clay*. This under-clay generally contains fossil plants, and especially the roots of Carboniferous plants called *Stigmariæ*, and it is regarded (as first shown by Logan) as the old dirt-bed in which the plants grew that commenced to form the coal bed. In some cases trunks of trees rise from it, penetrating the coal layer and rock above it.

The Nova Scotia Coal region abounds in erect trunks, standing on their old dirt-beds, as illustrated in fig. 560 (by Dawson).

Fig. 560.



Section of Coal Measures at the Joggins, Nova Scotia (with erect stumps in the sandstone, and rootlets in the under-clays).

Each of the 76 coal seams at the Joggins has its darker clayey layer, or dirt-bed, beneath. In 15 of them there is only a trace of

coal; but these, as well as the rest, contain remains of roots (*Stigmariæ*), and often support still the old stumps. (Dawson.)

The rock capping a coal bed may be of any kind, for the rocks are the result of whatever circumstances succeeded; but it is common to find great numbers of fossil plants and fragments of trees in the first stratum.

The shaly beds often contain the ancient ferns spread out between the layers with all the perfection they would have in an herbarium, and so abundantly that, however thin the shale be split, it opens to view new impressions of plants. In the sandstone layers, broken trunks of trees sometimes lie scattered through the beds. Some of the logs in the Ohio Coal measures, described by Dr. Hildreth, are 50 or 60 feet long and 3 feet in diameter.

The thickness of the coal beds at times hardly exceeds that of paper, and again is from 30 to 40 feet. The beds also vary in purity, from coal with but 1 per cent. of earthy matter, to dark-colored shales with only a trace of coal. The thickness is seldom over 8 feet, and the impurities ordinarily constitute from 7 to 15 per cent.

The Pittsburg seam, at Pittsburg, Pa., is 8 feet thick. It borders the Monongahela for a long distance, the black horizontal band being a conspicuous object in the high shores. It may be traced, according to Rogers, into Virginia and Ohio over an area at least 225 miles by 100; and even into Kentucky, according to Lesquereux. But it varies in thickness, being 12 to 14 feet in the Cumberland basin, 6 feet at Wheeling, 5 at Athens, Ohio, and on the Great Kanawha; farther south, at the Guyandotte, 2 to 3 feet.

The "Mammoth Vein," as it is called, which is exposed to view at Wilkesbarre, Pa., is 29½ feet thick. It is nearly pure throughout, although there are some black shaly layers 1 to 12 inches thick. The same great bed is worked at Carbondale, Beaver Meadows, Mauch Chunk, Tamaqua, Minersville, Shamokin, etc.

At Pictou, in Nova Scotia, one of the coal beds has the extraordinary thickness of 37½ feet, and a second 22½ feet.

2. *Structure of the Coal.*—A bed of coal, even when purest, consists of distinct layers. The layers are not usually separable, unless the coal is quite impure from the presence of clay; but they are still distinct in alternating shades of black, and may be seen in almost any hand specimen of the hardest anthracite, forming a delicate, though faint, banding of the coal.

In much of the bituminous coal of the Mississippi basin a cross-fracture shows it to be made up of alternate laminæ of black, shining, compact bituminous coal, and a soft, pulverulent carbonaceous matter, much like common charcoal.

The coal itself varies much in character. In some regions, as in the Schuylkill (at Pottsville, Mauch Chunk, etc.) and Wilkesbarre coal fields, at Peak Mountain, in Virginia, and in Rhode Island, it is of the kind called *Anthracite* (see page 68), which is non-bituminous, and burns with very little bluish flame. At Pittsburg, and through nearly all of the Appalachian coal field, and in the other coal areas of North America, it is *Bituminous* coal, which burns readily with a bright-yellow flame.

The bituminous coal is either the ordinary brittle kind, breaking into lustrous angular pieces, or the compact *Cannel coal*, distinguished by its firmness, slight lustre, conchoidal fracture, and the absence of any laminated structure. Cannel coal often graduates into ordinary bituminous coal.

In many places there are vegetable remains in the coal itself, such as impressions of the stems of trees, or leaves, or charcoal-like fragments which in texture resemble charcoal from modern wood. Fig. 561 *a* represents a specimen of this kind from Tuscaloosa, Ala., as figured by Bunbury: it has a fibrous appearance to the naked eye, but under a pocket-lens shows rectangular meshes over the whole (fig. 561 *b*), like the structure of the leaves of some water-plants.

Even the solid anthracite has been made to divulge its vegetable tissues. On examining a piece partly burnt, Professor Bailey

Fig. 561.

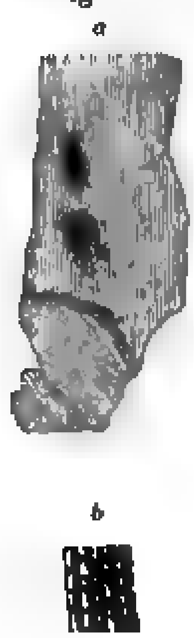
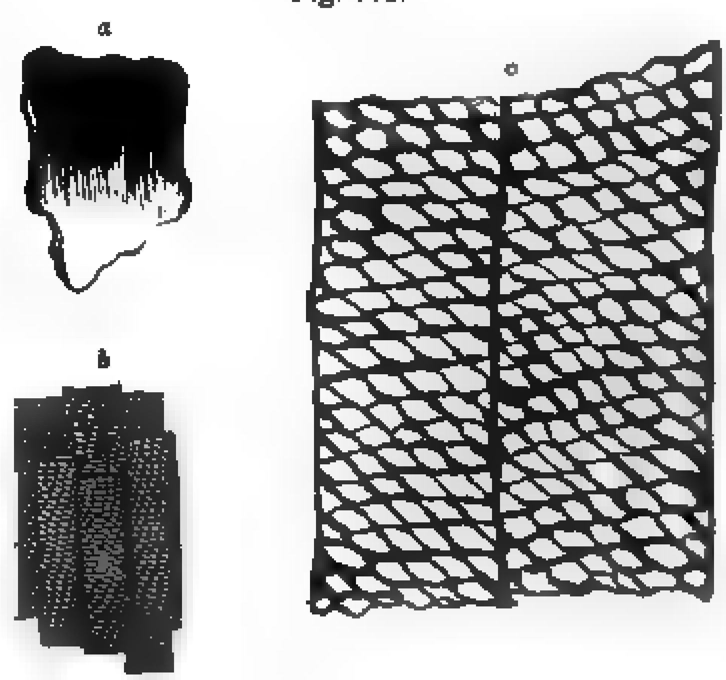


Fig. 562.



found that it was made up of carbonized vegetable fibres. The annexed figures 562 *a*, *b*, *c*, are from his paper on this subject. He

selected specimens which were imperfectly burnt (like fig. 562 *a*), and examined the surface just on the borders of the black portion. Fig. 562 *b* represents a number of ducts thus brought to light, as they appeared when moderately magnified, and fig. 562 *c* two of the ducts more enlarged; the black lines being the coal that remained after the partial burning, and the light spaces *silica*. The ducts were $\frac{1}{10}$th of a millimetre (about four-thousandths of an inch) broad. No stronger evidence could be had of the vegetable origin of anthracite coal.

Pyrites (sulphuret of iron, page 64) is sometimes disseminated through coal beds in nodules or seams, to the serious injury of the coal. Such coal crumbles down on exposure to the air, and gives forth sulphur fumes when burnt. Even the best of mineral coal contains traces of pyrites; and to this is owing the sulphur smell ordinarily perceived from coal fires.

3. *Iron-ores.*—The iron-ore beds are usually from a few inches to 3 or 4 feet in thickness. They contain the ore in concretionary masses or plates of a stony aspect. The most common but not most valuable kind has a grayish-blue and drab color on a fresh surface of fracture, and differs from limestone in being unusually heavy: this ore, called *clay-ironstone*, is an impure spathic iron or *chalybite* (p. 63). Another variety of *ironstone* is an impure *hematite* (p. 65), affording a red powder. Still another kind is an impure *limonite* (p. 65), having a reddish-brown or yellowish-brown color and affording a brownish-yellow powder: beds of this variety are few, but widely extended, thick, and valuable.

4. *Upper and Lower Coal Measures.*—The Coal measures are sometimes divided into the Upper and Lower Coal measures. The most convenient division is above the "Mammoth bed" of Pennsylvania,—as there is a marked change in the flora from this point. It has been proposed to make the Mahoning sandstone the dividing bed, above the Upper Freeport coal bed, which is the third above the so-called Mammoth bed in the Pennsylvania series. Another great sandstone stratum, called the Anvil Rock, occurs in Kentucky, above the twelfth Coal bed in the Kentucky series; and this has also been made a dividing stratum in the measures. There is nothing in the fossils that renders the subdivision at these places of geological importance. (Lesquereux.)

The great Anthracite region of Pennsylvania is largely Lower Carboniferous. The Upper Carboniferous is present there (at Pottsville, Shamokin, and Wilkesbarre) up to the top of the Pittsburg group (Lesley); but the rest does not extend so far eastward. The greatest development of the lower coal was in Pennsylvania; and of the upper, in the States farther west. The highest beds in the series appear to occur west of the Mississippi, in Kansas, where they merge into the Permian. There are, however, according to McKinley, 3000 feet of barren Coal measures above the level of the Pittsburg coal, in the southwest corner of Pennsylvania and the adjoining part of Virginia, and it is not certain how far upward they may reach in the series.

5. *Equivalency of the Appalachian and Illinois Coal Measures.*—There is great difficulty in arriving at safe conclusions as to the equivalency of the beds in

the different coal basins, because the beds of rock as well as of coal—even those that are the thickest—vary much at comparatively short distances over the country. Moreover, as the basins are wholly disconnected, there is no chance to trace even a single stratum from one to another. It is often assumed that the Appalachian and Illinois beds were once united, and were afterwards divided by the uplift of the Silurian about Cincinnati and extensive denudation accompanying it. But it has been shown (p. 317) that this uplift probably antedates long the Carboniferous Age; and, if this were so, the connection in those latitudes is impossible. It is evident, therefore, that only the most general conclusions on the subject of equivalency can be accepted as established facts. The principal investigations on this subject are those of Lesquereux, who has brought to it a thorough knowledge of the coal plants.

The Coal measures of Pennsylvania and the States west include twelve to eighteen distinct workable coal beds, besides thinner seams, the number varying in different regions from certain beds being comparatively local. In this series there are two beds that have special prominence on account of their thickness and the wide range they are believed to have.

There are, *first*, the *Mammoth Anthracite vein* of Pennsylvania, which is the second or third from the bottom, not far from the Millstone grit.

Second, the *Great Pittsburg bed*, the seventh or eighth above the Mammoth vein.

The following are the equivalents of these beds, according to Lesquereux:—

(1.) *Mammoth bed* (Second workable Pennsylvania bed).—The bed at Leonards, above Kittaning, Pa. (3½ feet thick), etc.; Mahoning Valley, Cuyahoga Falls, Chippewa, etc., Ohio; the Kanawha Salines; the Breckenridge Cannel Coal and other mines in Kentucky, the first (or second) Kentucky bed; the lower coal on the Wabash, Ind.; Morriss, etc., Ill.

(2.) *Pittsburg bed* (Eighth Pennsylvania bed).—Bed at Wheeling; at Athens, Ohio; the *Well* Coal, at Mulford's, in western Kentucky, the eleventh Kentucky bed.

The *Gate and Salem beds* correspond to the *Upper Freeport* (or fifth bed, western Pennsylvania); *Pomeroy* coal, Ohio, situated below the Mahoning sandstone; the *Curlew* coal, of Curlew Hill, Kentucky, or the fourth Kentucky bed.

In Kentucky, fifteen or twenty distinct coal beds exist. The eleventh is supposed to correspond to the Pittsburg bed, and the others are above it. Above the twelfth, there is the massive sandstone, 40 to 50 feet thick, called the *Anvil Rock*, from the form of two masses of it in southwestern Kentucky. Six or seven coal beds occur above the Anvil Rock, in about 500 feet of rock; but they are very thin; the whole amount of coal in this thickness is about 5 feet. (D. D. Owen.) The thickness of rock in the Coal measures below the top of the Anvil Rock is about 1000 feet, and of the included coal beds about 40 feet; making, in all, for the western Coal measures of Kentucky, a thickness of 1500 feet, in which are 45 feet of coal.

6. *Sections of the Coal Measures.*—In western Pennsylvania, the western Coal measures, to the top of the Upper Freeport Coal inclusive, consist, according to Lesley,* of the following beds. The numbering of Lesley by the letters of the

* Manual of Coal and its Topography, by J. P. Lesley, 12mo, 1856, Philadelphia. Lippincott & Co.

alphabet is added; and also that by Lesquereux (the latter in parentheses), as made out from a supposed parallelism between the Kentucky and Pennsylvania beds.

		Feet.
	Millstone Grit	?
1.	COAL No. A, with 4 feet of shale [1 A]	6
2.	Shale and mud rock	40
3.	COAL No. B [1 B]. (Equivalent of Mammoth bed)	3–5
4.	Shale, with some sandstone and iron-ore	20–40
5.	Fossiliferous Limestone	10–20
6.	Buhrstone and Iron-ore	1–1½
7.	Shale	25
8.	COAL No. C. The Kittaning Cannel (equivalent of the Cannel of Peytona, Va. and Darlington, Pa.) [2]	3½
9.	Shale,—soft, containing two beds of coal 1 to 1½ feet thick	75–100
10.	Sandstone	70
11.	Lower Freeport COÀL bed No. D [3]	2–4
12.	Slaty sandstone and shale	50
13.	Limestone	6–8
14.	Upper Freeport COAL, No. E of Lesley [4]	6
15.	Shales	50

The *Upper Coal measures* are continued in western Pennsylvania, to the Pittsburg coal inclusive, as follow:—

		Feet.
1.	Mahoning Sandstone	75
2.	COAL No. F [5]	1
3.	Shale; thickness considerable	?
4.	Shaly sandstone	30
5.	Red and blue calcareous marls	20?
6.	COAL No. G [6]	1
7.	Limestone, fossiliferous	2
8.	Slates and shales	100
9.	Gray clayey sandstone	70
10.	Red marl	10
11.	Shale and slaty sandstone	10
12.	Limestone, non-fossiliferous	3
13.	Shales	32
14.	Limestone	2
15.	Red and yellow shale	12
16.	Limestone	4
17.	Shale and sand	30
18.	Iron-ore (spathic)	25
19.	Limestone	1–1½
20.	Pittsburg COAL, No. H of Lesley [11]	8–9

The upper part of the *Upper Coal measures* (above the Pittsburg bed) in western Pennsylvania (Waynesburg, Greene co.), according to Lesley, includes, commencing below:—

	Feet.
1. Shale, brown, ferruginous, and sandy	30
2. Sandstone, gray and slaty	25
3. Shale, yellow and brown	20
4. Limestone,—the Great Limestone south of Pittsburg (including two COAL beds, 2½ feet and 1 foot)	70
5. Shale and sandstone	17
6. Limestone	1
7. Shale and sandstone	40
8. COAL	6
9. Shale, brown and yellow	10
10. Sandstone, coarse, brown	35
11. Shale	7
12. COAL	1½
13. Limestone 4 feet, shale 4, limestone 4, shale 3	15
14. Shale 10 feet, sandstone 20, shale 10	40
15. COAL	1
16. Sandstone (at Waynesburg), with 4 feet of shale	24

Sections of the strata of Kentucky, Missouri, Ohio, and Michigan, will be found in the Geological Reports on those States, and others of Nova Scotia in Dawson's Acadian Geology, and the Quarterly Jour. Geol. Soc. 1854, page 60. Mr. Lesquereux has published a memoir on the equivalency of the coal beds of the United States in the Geological Report of Kentucky.

The relations of the sandstones, limestones, and shales that alternate with the coal beds over the wide region stretching from the Appalachians west, are but partially understood. Although these strata seem to be generally limited in range, there is still an equivalency to be ascertained for the whole succession. The rocks, as in other ages, are consecutive records of the events of the period; and until fully elucidated, the history of the American Carboniferous era will remain imperfectly known.

III. Life.

1. *Plants.*

The abundance of Fossil Plants is the most striking characteristic of the Coal era; and the remains are so widely diffused, and are distributed through so great a thickness of rock and coal, that we may be sure we have in them a good representation of the Forest and Marsh as well as Marine Vegetation of the Carboniferous age. In the marine, there is little peculiar to note. The land-plants, on the contrary, afford evidences of progress in the life of the globe, and reveal an expansion of some departments of the Vegetable kingdom which would not have been suspected were it not for the evidence in the rocks

This vegetation began, as already shown, in the early Devonian, and was well displayed before its close. The general characters

of the flora have been mentioned on page 302. The tribes of plants are here repeated in tabular form:—

1. PHÆNOGAMS, or Flowering Plants; the inferior class GYMNOSPERMS. (See page 165 for the signification of the terms used in the classification of plants.)

a. True Conifers.

b. Sigillarids, related to the Conifers.

2. CALAMITES,—plants with jointed stems or trunks, supposed by Brongniart to rank nearer Gymnosperms than the Equiseta among Acrogens.

3. CRYPTOGAMS, or Flowerless Plants; the superior class ACROGENS.

a. Lycopodium or Ground-Pine family.

b. Ferns.

c. Equiseta.

The frontispiece may be again referred to for a general idea of the features and also the characteristic plants of the Coal era:—the *Lycopodium*, a large tree on the right of the picture, and another on the left; the *Sigillaria*, a broken stump in the right corner; the *Tree-fern*, a tree with spreading top near the centre of the picture, copied from a drawing of a modern species; ordinary *ferns*, the low plants with spreading leaves or fronds beneath the Tree-fern, etc., in the foreground.

Remains of *Fungi* (or Mushrooms) occur, but are not common; and these, with *Sea-weeds* (marine Algæ), are the only kinds of lower Cryptogams known to be present. There is no evidence of the existence of Mosses, Lichens, or Liverworts (Hepaticæ). Even the simple Confervæ (fresh-water Algæ), sometimes called frog-spittle, were not in the ponds of the Coal-era.

There were no Angiosperms, and, in all probability, no Palms or other Endogens.

A few remaining species of plants have been referred to the Grasses, Sedges, and Palms, and some small Endogens related to the Lily tribe. But these are rare and of uncertain determination. The order of Palms has been supposed to be represented in the genera *Flabellaria, Noeggerathia, Palmacites*, and *Trigonocarpum;* but the species are now believed to belong to other groups.

Although the vegetation was very largely cryptogamous, yet it was in a great degree *forest-vegetation.* Should we collect all the existing terrestrial Cryptogams of North America, in order to make a forest of them, the forest would hardly overtop a man's head, and the Ferns would have an undergrowth of toad-stools, mosses, and lichens.

Tree-ferns now grow only in the tropics. The largest modern

Lycopodia are four to five feet in height; the ancient were sixty to eighty feet. The Equiseta of our marshes are slender, herbaceous plants, with hollow stems, and, when of large size, little over two feet high; the Calamites of the Carboniferous marshes had partly woody trunks, and some were a score of feet, or more, in height.

The Conifers of the period were abundant, and were the *modern* feature in the Palæozoic forests. But these were in the main related to the Araucarian Pines (see p. 166),—a group which now lives in Araucania, Chili, and Brazil, on the continent of South America, and in Australia and Norfolk Island, in the South Pacific, and which are therefore confined in the Age of Man to the Southern hemisphere.

1. *Lepidodendron tribe* (*Lycopodium* or Ground-Pine family). The various genera (*Lepidodendron, Lepidophloios, Halonia, Knorria*, etc.) are confined to the Lower Coal measures. They were lofty woody trees, with scarred trunks and branches, the scars of which (figs. 563, 4, 5, 7) are arranged in quincunx order. These scars are the impressions left where the leaves or fronds dropped off, and are very similar to those observed on the trunks of modern tree-ferns, one of which is shown in fig. 575, and an ancient one in fig. 566.

Figs. 564–566.

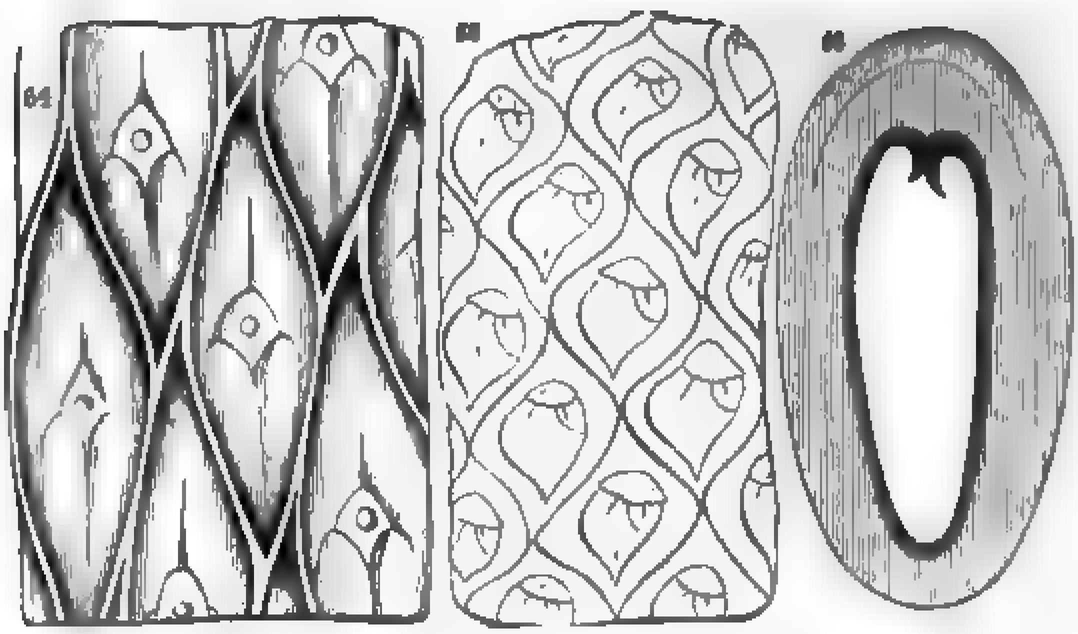
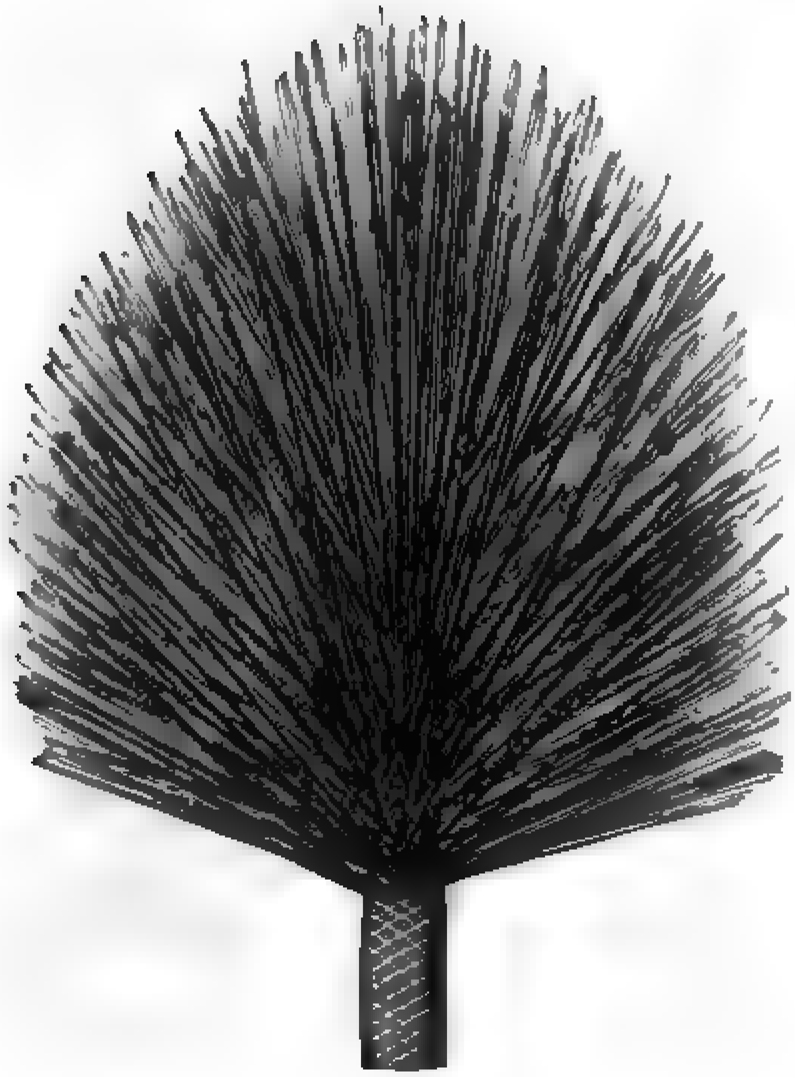


Fig. 564, Lepidodendron obovatum; 565, Lepidodendron clypeatum, 566, Caulopteris punctata (× ½), being one of the scars left on the stem of a tree-fern by the leaf-stalk.

Fig. 563, view—partly ideal—of the extremity of a branch of a *Lepidodendron*. The slender, pine-like leaves in the *Lepidodendron Sternbergi*, as shown in magnificent specimens from the coal-mines of Radnitz, in Austria, figured by

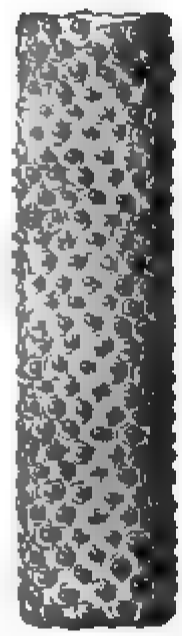
Ettingshausen, are over a foot long, and are as closely crowded about the branches as in any modern Pine. See also the trees on the frontispiece, above

Fig. 563.



Extremity of a branch of Lepidodendron, with the leaves attached.

Fig. 567.



Halonia pulchella.

referred to. Fig. 564, part of the surface of the *Lepidodendron obovatum* Sternberg, a common species both in the United States and Europe. Fig. 565, *L. clypeatum*. The cones (*Lepidostrobus*) found in the same rocks with the *Lepidodendra* are regarded as their fruit. They have some resemblance to the cones of Pines. Fig. 567 represents a portion of the stem of *Halonia pulchella* Lsqx., a plant similar to Lepidodendron, from the Coal measures of Arkansas.

2. *Sigillaria tribe.*—The *Sigillariæ* (figs. 568, 569) are most abundant in the Lower Coal measures, and appear to have taken a great part in the formation of the Coal. They are supposed to have grown over the great marshes of the era in which the Coal vegetation

accumulated, while the Lepidodendra and Conifers, though not excluded from the marshes, covered the drier hills and plains of the continent. Most of the Sigillariæ grew up as simple trunks to a height of thirty to sixty feet, without branches. The surface and summit were covered with long, narrow leaves in great numbers; and out of these leaves, found separate, the genera *Poacites* and *Cyperites* have been made. The trunk is usually ribbed vertically, and the scars are arranged along the ribs. The name of the genus alludes to the scars, and is from the Latin *sigilla*, *seals*. In both this group and the preceding, the appearance of the scars of the same species varies much with age, and upon the opposite sides of the bark the same scar is wholly different, as shown in figs. 568 and 569, in the part of each of which to the right an impression

Figs. 568–570.

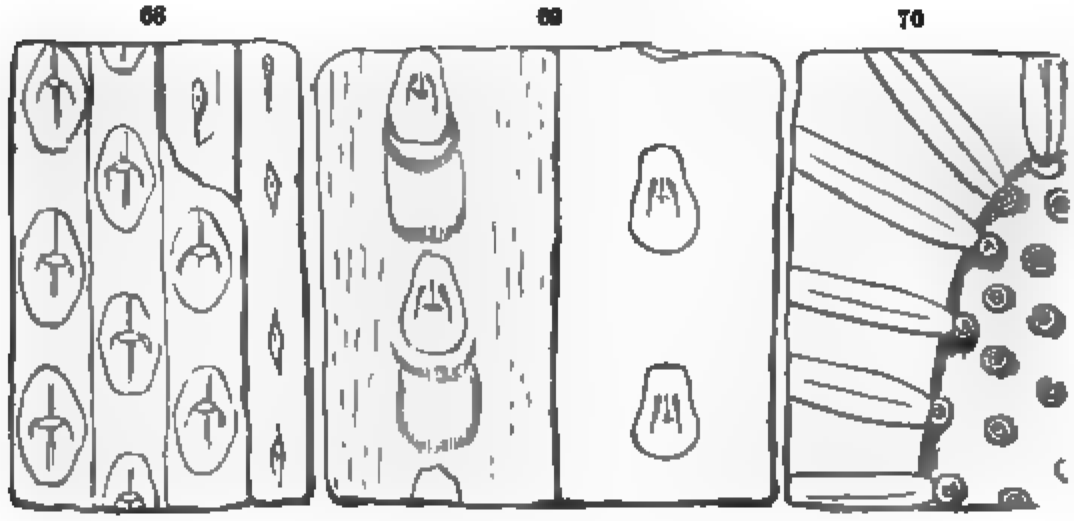


Fig. 568, Sigillaria oculata; 569, S. obovata; 570, Stigmaria ficoides.

of the inner surface of the bark is shown. The plant is proved to have been of close texture through the interior of the trunk, and still may have had a rapid growth. Stumps made hollow by decay within, and now filled with sand and clay and fossilized, are common in the Coal measures. Of many such, only casts in sand, showing an impression of the scarred exterior, remain.

Fig. 568 represents the *Sigillaria oculata*, from Trevorton, Pa.; 569, *S. obovata*, from Pennsylvania and Kentucky.

3. *Stigmariæ*.—The *Stigmariæ* were originally described as the remains of trees related to the *Sigillariæ*. The surface-impressions are very different, being simply scattered rounded depressions or prominences; and to each there is sometimes a long, leaf-like appendage, as in fig. 570, which represents a portion of a branch. But the branching roots of both Sigillariæ and Lepidodendra have been

found to have the characteristics of the *Stigmariæ;* and these roots often lie in great numbers in the under-clays of the coal beds. In Nova Scotia and England, *Sigillaria* stumps have been observed with *Stigmaria* roots. Lesquereux, however, maintains that the Stigmariæ are sometimes, at least, stems, and not roots.

Fig. 570 is the *Stigmaria ficoides*, a species which is said to have a range through the whole Coal measures,—which may be true if more than one species is not confounded under the name. *Sigillaria minuta* occurs in the Catskill epoch of the Devonian; other species, in the Upper Coal measures.

4. *Calamites.*—These jointed rush-like plants sometimes grew to a height of twenty feet or more, and were associates of the *Sigillariæ* in the marshes, being common throughout the Coal measures.

Fig. 583 represents *C. cannæformis*, one of the Lower Coal-measure species. *C. Cistii* Brngt. and *C. nodosus* Schlotheim are other American Lower-Coal species, as well as foreign; *C. Pachyderma* is found only in the Millstone grit below (Lesquereux).

5. *Conifers.*—Coniferous trunks and stumps are common through the Coal measures, and occur also far down in the Devonian. But it is remarkable that their leaves have been seldom found. The *Sternbergiæ*, which are abundant in Ohio, and at Pictou, Nova Scotia, have been shown by Dawson and Williamson to be casts of the pithy or open cellular interior of some Conifers. (See p. 283.) They are thick, cylindrical stems, much wrinkled circularly, consisting of the same arenaceous material as the rock in which they occur buried. Occasionally they have a carbonaceous exterior, which is the woody part of the former tree. In Nova Scotia specimens, as well as those of England, a coniferous structure has been observed in the coaly exterior, and also a very open cellular structure through the sandstone interior. The Devonian species from Pictou is not distinguishable in its microscopic structure from the *Pinites* (*Dadoxylon*) *Brandlingi* of Witham.

Most of the known Carboniferous species are related (*Dadoxylon* included) to the genus *Araucarites*. The American species of Carboniferous Conifers have been but little studied.

Fruits of Conifers and other plants.—Besides the remains of trunks of Conifers, various fruits are found in the Carboniferous beds. Those which have been referred to the genus *Trigonocarpum*, according to Hooker, are the fruit of Conifers, and resemble most that of the Chinese genus *Salisburia* of the *Yew* family (*Taxineæ*). According to Dawson, they are the fruit of Sigillariæ.

Figs. 571 to 574 (by Newberry) represent nuts or fruits from the Lower Coal: fig. 571 *a*, *b*, *c*, *d*, is *Trigonocarpum tricuspidatum* Newberry, *a*, the nut; *b*, the

kernel; *c*, the complete nut; *d*, the husk or rind enclosing the nut. Fig. 572 is *Cardiocarpum samaræforme* (the name of the genus, from *καρδία*, *heart*, alludes to

Figs. 571–574.

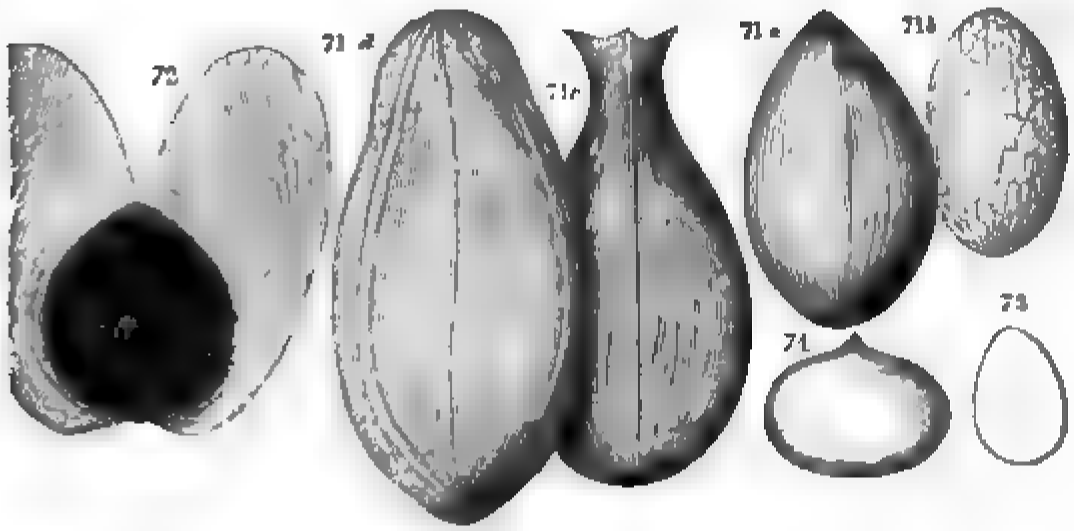


Fig. 571 *a*, *b*, *c*, *d*, Trigonocarpum tricuspidatum; *a*, the nut; *b*, the kernel; *c*, the complete nut, *d*, the husk or rind; 572, Cardiocarpum samaræforme; 573, C. elongatum; 574, C. bicuspidatum.

the common cordate form of the seed); fig. 573, *C. elongatum*; fig. 574, *C. bicuspidatum*. The Cardiocarpa are supposed to be the fruit of Lepidodendra.

6. *Ferns*.—The ferns are mostly of the low herbaceous kinds, although a few tree-ferns occur. Some of the fronds were six to eight feet in length.

In one group of Ferns, the *Neuropteridæ*, the leaves or leaflets have no mid-rib, as in *Cyclopteris*, *Noeggerathia*, *Odontopteris*, and *Neuropteris*. In another group, the *Sphenopteridæ*, the leaflets or lobes have a mid-rib slightly distinct, but it fails before reaching the apex, and the veins do not emerge from it, as in *Sphenopteris* and *Hymenophyllites*. In a third, the *Pecopteridæ*, the mid-rib is very distinct, and the veins emerge from it more or less obliquely, as in *Alethopteris*, *Pecopteris*, *Callipteris*, *Asplenites*.

Fig. 566 represents the scar on the surface of an American species of fossil tree-fern, *Caulopteris punctata* Lsqx., from the Gate vein, Pennsylvania. For comparison, the scar of a modern tree-fern, fig. 575, is here given, from the species *Cyathea compta*, occurring in the islands of the Pacific. With the growth of the tree (see sketch near middle of frontispiece), as new fronds are unfolded, the old ones drop off, each of which leaves its scar analogous to the above. The manner in which the fronds of ferns unroll as they expand is shown in the figure here referred to.

Fig. 575.

Scar of a recent tree-fern (×½).

Fig. 576, *Neuropteris Loschii* Brngt., and fig. 577, *Neuropteris hirsuta* Lsqx., from figures by Lesquereux, both very common in the Upper Coal measures in Ohio and Kentucky, and the former particularly abundant in the Pomeroy bed. Fig. 579, *Pecopteris arborescens* Brngt., common in Pennsylvania and Ohio. *P. Cyathea* Brngt., and *P. unita* Brngt.,

are also common in the United States, occurring in the Rhode Island coal fields as well as elsewhere. *Alethopteris Serlii* Göpp. is another common species of the Upper Coal measures, which is found also in Europe. Fig. 580, *Cyclopteris elegans* Lsqx., found in the Shamokin Coal bed, Pennsylvania.

In Arctic America, on Melville Island, impressions of a *Sphenopteris* have been observed in connection with the coal.

Figs. 576–583.

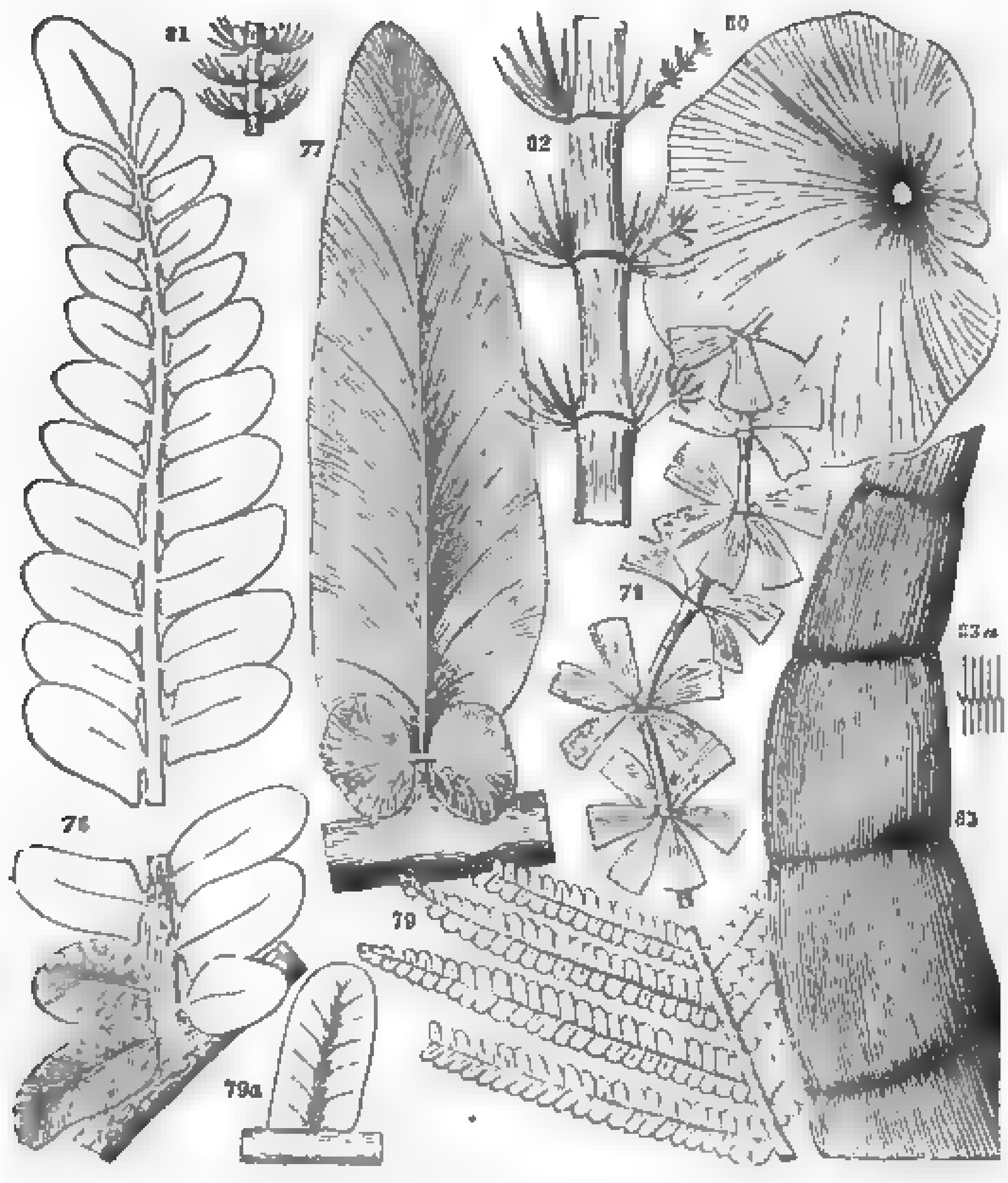


Fig. 576, Neuropteris Loeschii; 577, Neuropteris hirsuta; 578, Sphenophyllum Schlotheimii; 579, Pecopteris arborescens; 579 *a*, a portion of the same, enlarged; 580, Cyclopteris elegans; 581, Asterophyllites ovatus, with the nutlets in the axils of the leaves; 582, A. sublævis; 583, Calamites cannæformis; 583 *a*, surface-markings of same, enlarged.

The genus *Odontopteris* is mostly of the Lower Coal measures. Fig. 584, portion of a frond of *O. Schlotheimii*, from Pennsylvania and Europe; the whole frond is tripinnately divided, and of very large size. All the species of *Hymeno-*

phyllites, and several of *Alethopteris, Neuropteris*, and *Pecopteris*, are found in the lower division. Fig. 585, *Alethopteris Lonchitidis*, exclusively of the Lower Coal. *Sphenopteris tridactylis* Lsqx. is also from the Lower Coal. Fig. 586,

Figs. 584-587.

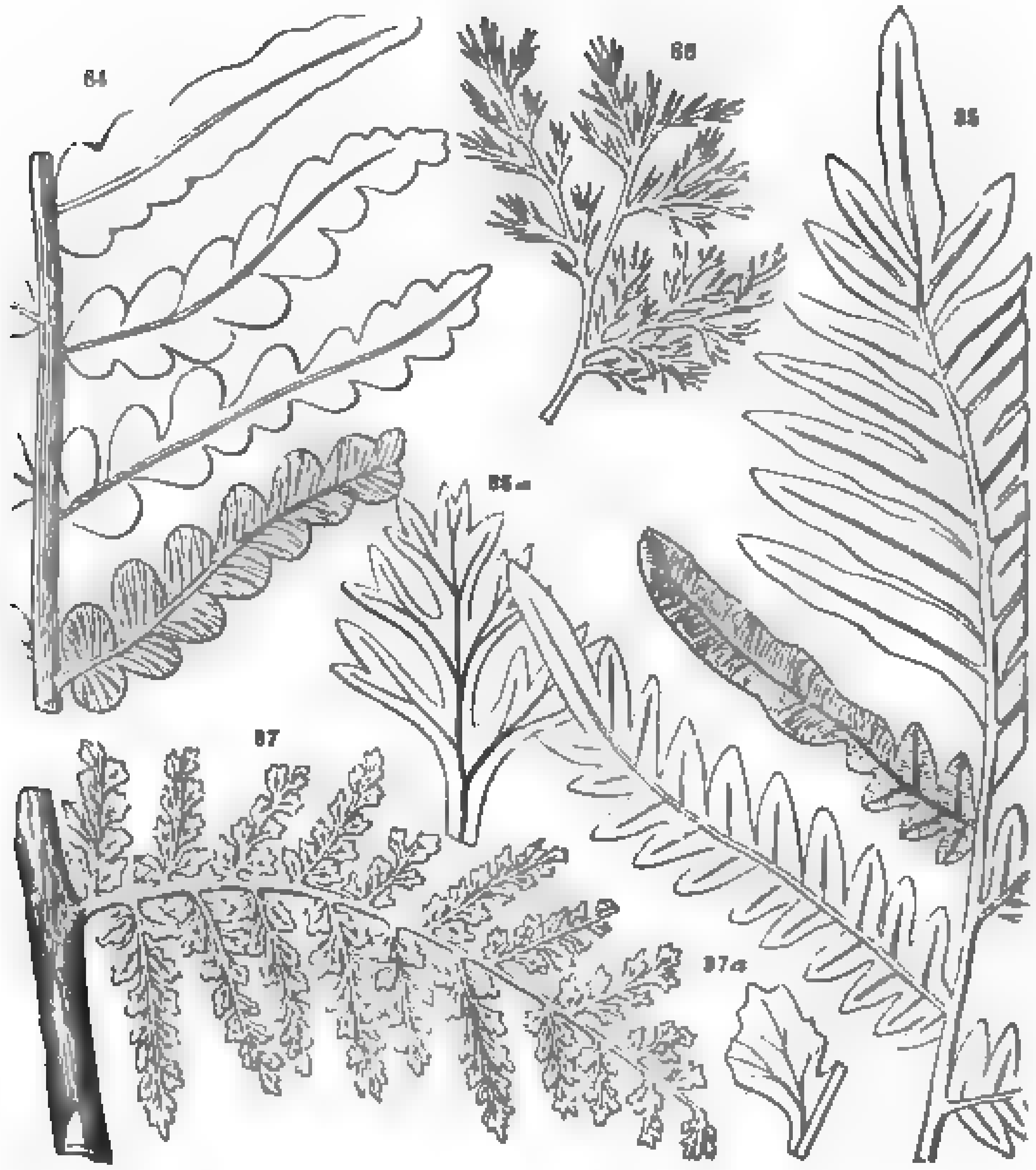


Fig. 584, Odontopteris Schlotheimii; 585, Alethopteris Lonchitidis; 586, Hymenophyllites Hildrethi; 586 *a*, portion of the same, enlarged; 587, Sphenopteris Gravenhorstii; 587 *a*, portion of the same, enlarged.

Hymenophyllites Hildrethi, from the Kanawha Salines, and 586 *a*, the same, enlarged; fig. 587, *Sphenopteris Gravenhorstii*, common in Ohio and farther west, at the Gate Vein, Pennsylvania, and occurring also in England and Silesia; 587 *a*, a portion of the same, enlarged.

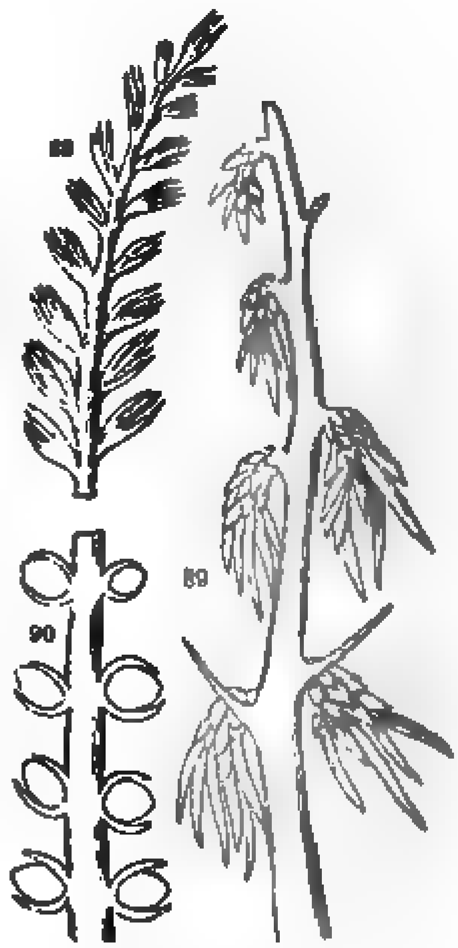
The genus *Noeggerathia*, a Devonian species of which is figured on p. 291, occurs in the Lower Coal measures alone. Fig. 587 A, *Noeggerathia minor* Lsqx., from Pennsylvania.

Another group of Coal plants is the *Asterophyllites* family, having some resemblance to Equiseta. It includes flexible herbaceous species, with leaves arranged in a circle or whorl at joints in the stem, whence the name, from *ἀστήρ, star*. They are confined to the Upper Coal measures. In the genus *Asterophyllites* the leaves are slender; and in *Sphenophyllum* (from the Greek *σφήν, a wedge*) they are obtuse and wedge-shaped, being smallest at base. Fig. 582, *Asterophyllites sublævis*; fig. 581, *A. ovatus*, with the nutlets in the axils of the leaves; fig. 578, *Sphenophyllum Schlotheimii* Brngt., from Pennsylvania, Salem and Gate veins, and Pomeroy beds, Ohio. Dr. Newberry regards some species of

Fig. 587 A.

Noeggerathia minor.

Figs. 588–590.



Flowers, and Fruit.

both genera as parts of the same plant, the former the submerged part, and the latter that which is emerged or rests upon the water. *Annularia* is another genus of this family. One species of it is represented in fig. 616 B.

Figs. 588–590 represent branches, with what seem to be the remains of flowers and fruit, discovered by Dr. Newberry in the Ohio Coal measures. Some specimens of this general character have been regarded by Hooker as young or partially-developed leaf-buds. It is, however, difficult, according to Dr. Newberry, to explain the specimens on that hypothesis.

The species of Coal plants of the American coal fields, thus far

observed, number about 350. 150 species have been procured from a single coal bed in Ohio by Dr. Newberry.

Characteristic Species of some of the subdivisions of the Carboniferous.

Lesquereux enumerates the following among the species characteristic of the groups below mentioned:—

(*a.*) *Subcarboniferous beds.*—*Stigmaria Anabathra* Corda, *S. minor*, *S. undulata*, and others; *Lepidodendron Veltheimianum* Sternb., *L. Worthianum*; a *Caulopteris*; a *Megaphytum*; *Calamites Suckowii* Brngt.; a *Bornia*; *Cordaites borassifolia* Ung., *Knorria imbricata* Sternb. Of these, the first of them, with the *Calamites*, *Cordaites*, and *Lepidodendron Worthianum*, occur higher in the series, and the *Calamites* and *Cordaites* continue through the whole Coal measures, or at least above the Pittsburg coal bed.

(*b.*) *Millstone Grit.*—*Lepidodendron*, six species; *Sigillaria*, two; *Calamites*, two; *Stigmaria*; and the Ferns, *Pecopteris velutina* Lsqx., *P. nervosa* Brngt., *Neuropteris flexuosa* Brngt., *N. hirsuta* Lsqx., *Annularia sphenophylloides* Ung., *Odontopteris crenulata*, *Hymenophyllites furcatus* Brngt., *Sphenopteris latifolia* Brngt., which occur also higher, to at least Coal bed No. 1 B.

(*c.*) *Mammoth Bed* (No. 1 B).—A great number of fruits, including nearly all of the Coal measures, of the genera *Trigonocarpum*, *Cardiocarpum*, *Rhabdocarpus*, and *Carpolithes*; numerous *Lepidodendra* (eighteen species); *Alethopteris Lonchitidis*, and *A. marginata*, not known above, and species of *Callipteris*, with few of the finer forms of the family, of the genus *Pecopteris*; among which few there are the *Pecopteris velutina*, *P. Sillimani*, *P. plumosa* Brngt.; *Sphenopteris* family numerously represented,—*e.g.*, *S. latifolia* Brngt., *S. obtusiloba* Brngt., *S. glandulosa* Lsqx., *S. polyphylla* Lindley & Hutton, *S. Newberryi* Lsqx., *S. artemisiæfolia* Brngt., and *Hymenophyllites Hildrethi* Lsqx., and *H. spinosus* Göpp., all peculiar to it; all the American species of *Odontopteris*, except *O. crenulata*, found also in the Millstone grit. Many *Sigillariæ*, as *S. stellata* Lsqx., *S. Serlii* Brngt., *S. tesselata* Brngt., *S. Brochanti* Brngt., *S. alveolaris* Brngt., and others, not found above. The most abundant species are the omnipresent *Neuropteris hirsuta* and *N. flexuosa*. There are also species of *Annularia*, *Sphenophyllum*, *Asterophyllites*, and *Calamites*; and everywhere *Stigmaria ficoides*.

(*d.*) *Coal No.* 4.—This bed is characterized by small Ferns. There are no *Lepidodendra*, but some *Sigillariæ*; and numerous species of the *Pecopteris* family; also species of *Asterophyllites*, many of *Neuropteris*, and several of *Sphenopteris*.

(*e.*) *Coal No.* 11, *the Pittsburg Coal bed.*—There are *Neuropteris hirsuta* Lsqx., *Cordaites borassifolia*, *Neuropteris flexuosa* Brngt., *Pecopteris polymorpha* Brngt., *P. arborescens* Brngt., *P. Cyathea* Brngt., *Sphenophyllum emarginatum* Brngt.; *Calamites*, three species; *Sigillaria*, one species; *Lepidodendra*, none. *Neuropteris Moorii* Lsqx. begins here, and has some resemblance to an Oolitic species.*

* See, for further detail, Lesquereux's Memoir, Am. Jour. Sci. [2] xxx. p. 367

2. *Animals.*

The animal life of the Coal measures is either (1) of land or fresh-water origin; (2) of brackish-water origin; or (3) of marine origin; and this is the first of the ages in which this distinction has been proved by actual discovery to have existed, although probably a fact in at least the latter half of the Devonian. Most of the limestones and some of the sandstones and shales contain marine fossils; while, on the contrary, other deposits of sand and clay bear evidence that they are not of the sea, any more than is the vegetation which covered the lands.

The species include, among PROTOZOANS, the little *Fusulina* of the Rhizopod group, a shell consisting within of minute cells, and related to the Nummulites of a later period. (See fig. 193, p. 164.)

Among RADIATES, Corals and Crinoids, both Palæozoic in type.

Among MOLLUSKS, numerous Brachiopods, *Spirifers* and *Producti* being especially abundant; Conchifers; Gasteropods, the species for the most part without beaks to the shells; Cephalopods of the genera *Nautilus*, *Goniatites*, and *Orthoceras*. A Palæozoic cast is apparent throughout.

But, while thus Palæozoic in marine life, there is a new *terrestrial* feature in the appearance of *land-snails* of the modern genus *Pupa*, belonging to the highest group of Gasteropods, the *Pulmonates*.

Among ARTICULATES, there is, in nearly all of the departments, a rise above the peculiarly Palæozoic grade, for Trilobites are rare; and—what is of still more progressive aspect—there are Insects and also Myriapods (Centipedes).

Among VERTEBRATES, the fishes are all of Palæozoic cast. They comprise only *Ganoids* and *Selachians*. The Ganoids have vertebrate tails, and the Selachians belong to the two extinct tribes of *Cestracionts* and *Hybodonts*,—the latter commencing with the Carboniferous age.

But there are also Reptiles, *air-breathing* Vertebrates; and these are new types, prophetic of the Reptilian age, which was next to follow. These early Reptiles* are (1) *Amphibians*, allied to the frog

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* The following are the general characteristics of Reptiles and of their subdivisions:—

Reptiles are cold-blooded animals, like Fishes, but air-breathing, like birds and quadrupeds. They are of low vital activity, with the temperature variable and in general directly related to that of the surrounding medium. The vertebræ differ from those of mammals in being convex and concave at the opposite ends, and in a few cases concave at both extremities, approximating, in this last

and Salamander, and in part, if not altogether, of the tribe of *Labyrinthodonts*, having the body covered with scales; (2) *Lacertians*, or inferior species of the Lizard tribe; (3) Swimming Saurians (*Enaliosaurs*, or sea-saurians, as the word signifies), allied to the *Ichthyosaurs*

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case, to those of fishes. The teeth, when set in sockets, never have more than one prong of insertion, while those of Mammals may have two or more. They are of two types, which are so fundamentally distinct that they require the division of the class into two sub-classes.

I. AMPHIBIANS.—Breathing when young (or in the tadpole state) by means of gills, and, with a few exceptions, undergoing a metamorphosis in which they become gill-less. Heart with two cavities, as in Fishes.

II. TRUE REPTILES.—Having no gills at any period of life, and undergoing no metamorphosis. Heart with three or four cavities.

I. AMPHIBIANS (BATRACHIA of most authors).

The Amphibians are the inferior type, and by some zoologists they are regarded as an independent class, intermediate between Reptiles and Fishes. The skeleton is distinguished by having (1) two occipital condyles for the articulation of the head with the body, one placed either side of the foramen; (2) the ribs very short, or rudimentary, or wanting; (3) the skull flat and usually broad, and of a loose and open structure. The body in living species is covered with a soft skin, with sometimes minute scales, as in the Cæcilians. In an extinct group there are distinct scales; and these species in this and other ways approach the true Reptiles.

There are three tribes among living species, and a fourth of extinct species, if not also a fifth.

1. CÆCILIANS, or Snake-like Amphibians.—Body having the form of a snake; no feet.

2. SALAMANDROIDS, or *Batrachia Urodela*.—Body usually lizard-like, or resembling in form a tadpole; having short legs, as in the Salamanders; sometimes, as in *Siren*, only the two fore-feet developed; ribs short. They graduate downward into species that keep their gills through life, which, while perfect animals, are representatives of the embryonic or young state of the higher Amphibians. In others of intermediate grade the gill-opening is retained, but not the gills. But in the large majority the gills and gill-openings both disappear.

Among the Salamandroids,—

Some retain their gills through life, as the *Siredon*, or *Axolotl*, of Mexico and western North America, *Siren* and *Necturus* of the United States, and *Proteus* of the Adelsberg Cave, Carniola.

Others retain the gill-openings, but not the gills, as *Menopoma* of the Alleghany region. The animals are large, broad, and flat, sometimes over two feet long. The *Amphiuma* of the Southern States is another example. The *Megalobatrachus* (or *Sieboldia*) is closely related, although the gill-openings become closed up; it is the largest of the existing tailed Amphibians, having a length exceeding three feet. The fossil *Andrias Scheuchzeri* is a Tertiary species related to it.

of the Mesozoic. Remains of three or four of the Reptiles were found at the Joggins in Nova Scotia, in the interior of a *Sigillaria* stump, which had become partly hollowed out by decay and afterwards filled by sand and mud in the marsh or forest where it stood,

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Salamandrids.—Species without gills or gill-openings in the adult state.

In most of the North American Salamandrids there are teeth on the vomer, and no parotid gland; while the species of Europe want these vomerine teeth, and have parotid glands.

3. Batrachoids (so named from the Greek *βατραχος, a frog*), or *Batrachia Anoura.* Body having four long legs (the hinder the longer) and no tail; as in the toads and frogs. The teeth are small, and mostly on the roof of the mouth on the vomer, with none in the lower jaw; the vertebræ are typically ten, but sometimes coalesce so as to appear fewer, the apparent number seldom exceeding eight; the ribs are wanting.

4. Labyrinthodonts.—The species of this group of extinct Amphibians resemble the Batrachoids in having (1) double occipital condyles; (2) teeth on the vomer; (3) short, if any, ribs; (4) usually large palatine openings: and they approach Saurians in having (1) the teeth stout and conical, and set in sockets; (2) the body covered with plates or scales; (3) the size sometimes very great. The teeth have the labyrinthine arrangement of the dentine and cement that characterizes the Sauroid fishes among Ganoids (see fig. 481), and which is still continued in that group among the living Gars; and hence the name *Labyrinthodonts.*

The Ganocephala are supposed by some to be related to the inferior Salamandroids, while approaching Ganoid fishes in the sculptured bony plates which covered the head, and in some other characters.—Ex., *Archegosaurus* and *Apateon.* Agassiz considers them, on good grounds, true Ganoids.

II. True Reptiles.

The skeleton in the true Reptiles has (1) but one occipital condyle below the foramen; (2) a series of ribs; (3) a covering of scales or plates, with rare exceptions.

The existing species, and part of the extinct, belong to three tribes:—

1. Snakes, or Ophidians.—(1) Body without legs with rare exceptions; (2) no sternum; (3) eyes without lids; (4) no external ear.

2. Saurians.—Body (1) without a carapax and with a tail; and having (2) four feet (rarely two, or none); (3) a sternum made usually of two united vertebræ, sometimes of more; (4) eyes with lids, or seldom without; (5) usually an external ear-opening.

3. Turtles, or Chelonians.—Body having (1) a carapax, or shell, made of several pieces firmly united; (2) a very large sternum forming the under surface of the body; (3) a horny beak instead of teeth; (4) an external ear-opening; (5) neck and limbs very flexible. The Chelonians have many marks of superior rank. But the species appear to be analogous to birds among the higher vertebrates, or the bats among mammals,—that is, inferior in grade, because they are of a small type or life-system, such as are styled *microsthenic* in the remarks on mammals. (See under the Triassic period, p. 421.)

before its final burial by the deposits that were increasing around it; and along with mineral charcoal derived from the wood, and the bones of the Reptiles, there were also more than fifty shells of the land-snail *Pupa vetusta*, and the Myriapod above alluded to, besides

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Saurians.—The Saurians vary in length from a few inches to fifty or more feet. In some the teeth are set in sockets,—whence they are called Thecodont Saurians (from θήκη, *a case*, and ὀδούς, *tooth*). In others (Pleurodonts) the teeth are implanted in a groove, the outer border of which projects more than the inner; in others (Acrodonts) they are soldered firmly to the salient part of the jaw-bone.

The prominent tribes are as follow, beginning with the highest in rank:—

1. Dinosaurs (δεινός, *terrible*, and σαῦρος, *a lizard*).—Reptiles of great size, all now extinct, having many mammalian characteristics: (1) the long bones have a medullary cavity; (2) the feet are short, and, with the exception of the ungual phalanges, like those of pachyderms; (3) the sacrum consists of at least *five* united vertebræ; (4) the lower jaw in some species has lateral motion for trituration. (Pictet.) Include the huge *Megalosaur, Hylæosaur, Iguanodon*, etc. In the sacrum made up of five united vertebræ, and some other characters, these species approach the mammals, and show their superiority to all other Reptiles.

2. Crocodilians, or *Cuirassed Saurians*.—Body having (1) a cuirass made of bony plates; (2) large, conical teeth in sockets in a single row; (3) one jugale; two premaxillary bones; (4) sacrum formed in general of two vertebræ; (5) heart with four cavities; external nostrils at the extremity of the snout. The modern species have *concavo-convex* vertebræ,—that is, the anterior face is concave and the posterior convex; in others, as the extinct *Cetiosaur* and *Steneosaur*, they are *convexo-concave;* and in a third group, including the extinct *Teleosaur, Macrospondylus*, etc., they are *doubly concave*.

3. Lacertians, or *Scaly Saurians*.—Body having (1) corneous scales; (2) the teeth rarely in sockets; (3) no jugale; one ventricle, one premaxillary bone; (4) sacrum consisting of two vertebræ at the most. The *Lizards, Iguanas*, and *Monitors* are the types of the tribe.

A few extinct species characterized by small scales are *Thecodonts*, like the Crocodiles, so that they stand apart from other Lacertians, and are intermediate between them and Crocodilians. Such are the *Thecodontosaur, Palæosaur*, and *Proterosaur* (fig. 617 A),—among the earliest of true Reptiles, and the precursors of the Crocodiles and Dinosaurs.

The *Mosasaur* (fig. 792), on the contrary, although of large size (twenty-five feet long), had the teeth inserted in a groove, as in the modern Lacertians. The same was the case with the *Geosaur;* and both are related to the *Monitor* of the Nile (*Varanus Niloticus*).

Besides these tribes, there are two extinct groups:—

4. Enaliosaurs (from ἐνάλιος, *marine*, etc.), or *Swimming Saurians*.—(1) Furnished with paddles for swimming; (2) having the vertebræ biconcave,—another fish-like characteristic; (3) teeth large, and set in a groove. *Ichthyosaur* and *Plesiosaur* are the most common genera. (See figs. 703–713, 715.)

5. Pterosaurs (from πτερόν, *a wing*, etc.), or *Flying Saurians*.—The most common genus is *Pterodactyl* (fig. 739). By the excessive elongation of the little finger of

fragments of many other specimens of the *Pupa*, and a few individuals of a small *Spirorbis*, the spiral shell of a worm of the Serpula tribe. The figure on p. 326 (fig. 560) represents a section of the part of the Coal measures in which these remains were found: the stump was twenty-two inches in diameter and nine feet high. The first discoveries at this place were made by Dawson and Lyell, in 1851. Dawson observes that the shells were probably the food of the Reptiles, adding that he has found in the stomach of a recent *Menobranchus* (*M. lateralis*) as many as eleven unbroken shells of the fresh-water snail *Physa heterostropha*.

Such a congregation of animals in a single stump proves, as Dawson states, that the species of the tribes represented were not rare in the marshes and forests of Carboniferous Acadia.

A *terrestrial* feature thus appears in three out of the four sub-kingdoms,—the Molluscan, Articulate, and Vertebrate. There are land and fresh-water shells in the first; Insects and Myriapods (or Centipedes) in the second; Amphibians and other Reptiles in the third. The Radiate sub-kingdom contains no terrestrial species, and hence did not admit of the same kind of progress.

Characteristic Species.

1. **Protozoans.**—*Rhizopods.*—*Fusulina cylindrica* and *F. elongata*, resembling fig. 193, p. 164. The first is a Russian species, and there is some question whether the American is identical with it. It occurs in vast numbers, almost making up the limestones in some places, and has been observed in Ohio, Illinois, Missouri, and Kansas. In the United States the genus *Fusulina* is confined to the Coal measures; but in Russia it occurs also in the Subcarboniferous rocks.

2. **Radiates.**—(*a.*) *Polyps.*—The Coral *Cyathaxonia prolifera* McChesney, from Illinois. (*b.*) *Echinoderms.*—*Crinoids* of the genera *Poteriocrinus*, *Actinocrinus*, etc.; *Echinoids* of the Palæozoic genus *Archæocidaris*.

3. **Mollusks.**—(*a.*) *Brachiopods.*—Fig. 591, *Spirifer cameratus* Morton (*S. Meusebachanus* Roemer), from the Lower and Upper Coal measures, and occurring in Ohio, Kentucky, Illinois, Missouri, Kansas, Texas, New Mexico, and Utah. This species is closely allied to *S. striatus* (figs. 211, 212, p. 181), and is

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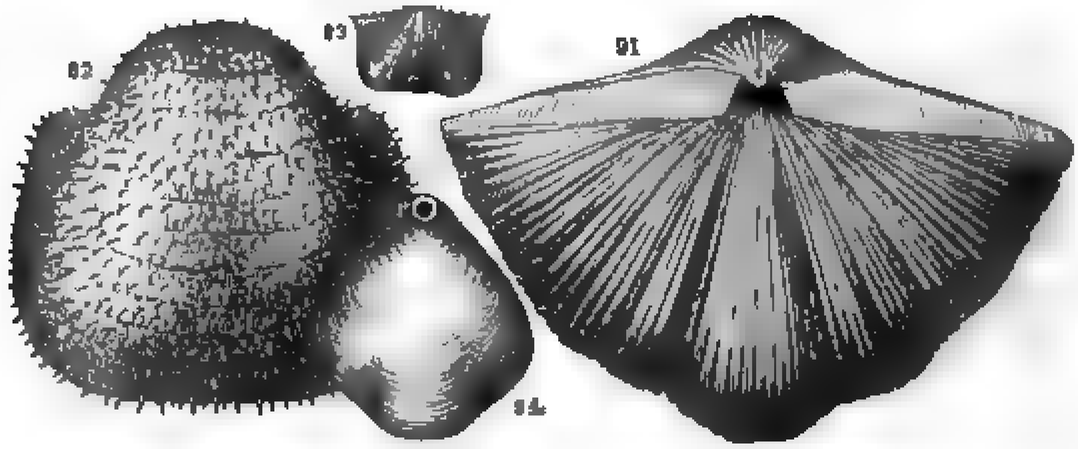
the fore-feet, support was afforded to a membrane which extended to the tail and made a wing for flying. The remaining fingers were short and furnished with claws. The long, slender jaws were set with a large number of teeth in a groove. The bones were hollow and light, as in birds. They had the habits of bats, and wings of a similar character. But in bats, all the fingers of the hand but the thumb are elongated for the purpose of the wing, and the thumb alone is used for clinging.

Chelonians.—The Turtles, or Chelonians, are of two tribes:—

1. The *Sea-Turtles*,—furnished with paddles instead of feet.
2. The *Land-Turtles*,—furnished with feet.

regarded by some as only a variety of it; but it belongs exclusively, in this country at least, to the Coal measures, and not to the Subcarboniferous in which the *S. striatus* is found well marked. Fig. 592, *Productus Rogersi* Norwood &

Figs. 591-594.

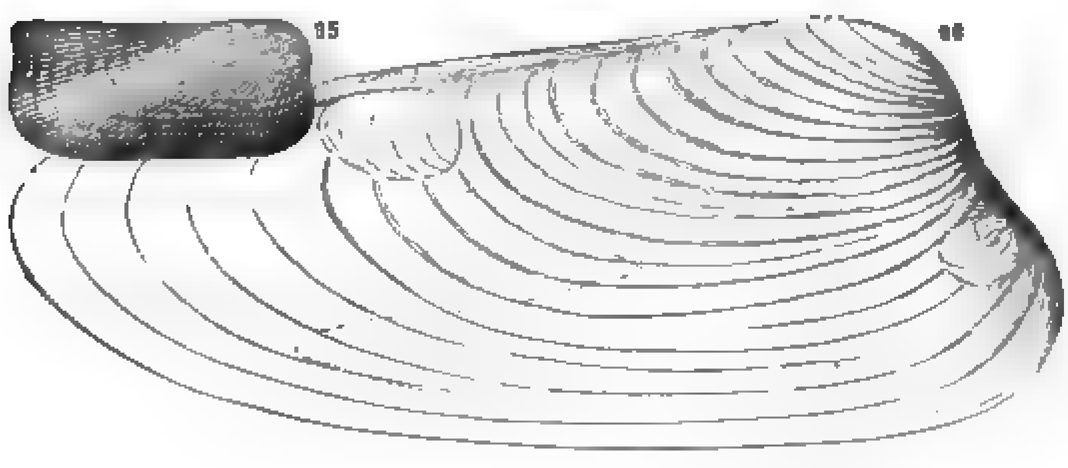


BRACHIOPODS.—Fig. 591, Spirifer cameratus; 592, Productus Rogersi; 593, Chonetes mesoloba; 594, Athyris subtilita.

Pratten, from Illinois, Kansas, and New Mexico; fig. 593, *Chonetes mesoloba*, a common species; fig. 594, *Athyris* (Terebratula) *subtilita*, very common in the Coal measures, and not known in the American Subcarboniferous, although reported from the latter in England. There are, however, Subcarboniferous forms distinguishable with difficulty from it. *Spirifer Kentuckensis* is an Upper Coal-measure species from Kentucky, Missouri, and near Pecos village, New Mexico.

The following first appeared in the Subcarboniferous, and are continued into

Figs. 595, 596.



CONCHIFERS.—Fig. 595, Arca (?) carbonaria; 596, Allorisma subcuneata.

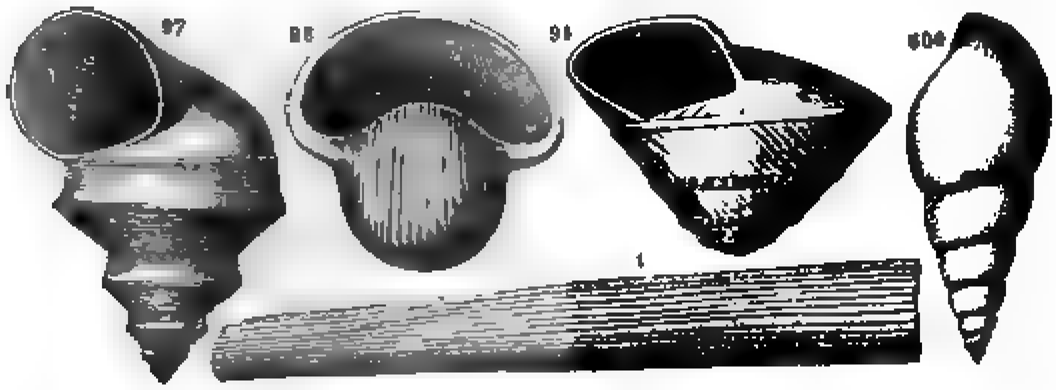
the Carboniferous: *Productus punctatus* (fig. 545, p. 314), *P. Cora*, *P. muricatus*, *P. semireticulatus* (fig. 229, p. 183), *Spirifer lineatus*.

(*b.*) *Conchifers.*—Fig. 595, *Arca* (?) *carbonaria* Cox, Upper Coal measures of Kentucky; fig. 596, *Allorisma subcuneata*, from Kansas. *Aviculopecten recti-*

laterariа, from the Upper Coal measures, Kentucky. *Pecten* [*Aviculopecten*] *aviculatus* Swallow, Kansas; *Pinna peracuta* Shum., Missouri, Kansas; *Lima* [?] *retifera* Shum., Kansas; *Mytilus* [*Modiola?*] *Shawneensis* Shum., Kansas.

(*c.*) *Gasteropods.*—Fig. 598, *Bellerophon carbonarius* Cox (often referred to *B. Urii*), Upper Coal, Kentucky; fig. 597, *Pleurotomaria tabulata*; fig. 599, *P. spherulata*; fig. 600, *Macrocheilus? fusiformis*; *Murchisonia minima* Swallow,

Figs. 597–601.



GASTEROPODS.—Fig. 597, Pleurotomaria tabulata; 598, Bellerophon carbonarius, 599, Pleurotomaria spherulata; 600, Macrocheilus? fusiformis; 601, Dentalium obsoletum.

Missouri; fig. 601, *Dentalium obsoletum.* Also the *Land-snail* (Helix family) *Pupa vetusta* Dawson (fig. 601 A), half an inch long; from the Coal measures of the Joggins, Nova Scotia.

(*d.*) *Cephalopods.*—*Nautilus Missouriensis* Shum., Lower Coal measures, *N. planivolvus* Shum., Upper C. M.; *Goniatites politus* Shum., near Middle C. M.; *G. parvus* Shum., Upper C. M.; *Orthoceras aculeatum* Swallow, Upper C. M.; *O. moniliforme* Swallow, Upper C. M.,—all from Missouri.

4. Articulates —(*a.*) *Worms.*—A species of Serpula of the genus *Spirorbis*, Coal beds of Nova Scotia.

(*b.*) *Crustaceans.*—*Trilobites*: *Phillipsia Missouriensis*, *P. major*, *P. Cliftonensis*,—all described by Shumard,—from the Upper Coal measures of Missouri.

Fig. 601 A.

Fig. 602.

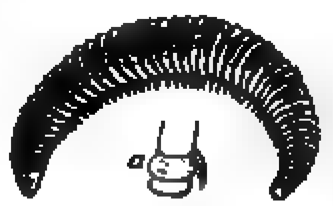


Fig. 602 A.

Fig. 601 A, Pupa vetusta (× ½); 602, *a*, MYRIAPOD: Xylobius Sigillariæ; 602 A. INSECT-WING, Blattina venusta.

Ostracoids: *Beyrichia Americana* Shumard, from Missouri; also species resembling those of the fresh-water genus *Cypris* in Nova Scotia.

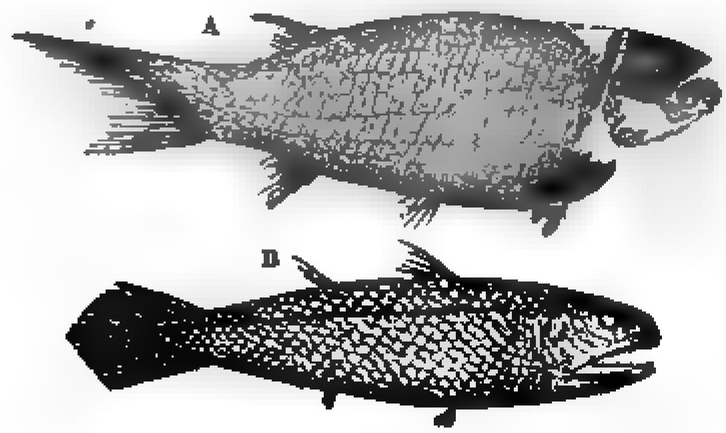
(*c.*) *Myriapods.*—Fig. 602, *Xylobius Sigillariæ* Dawson, from the Coal measures of Nova Scotia, and supposed to be related to the modern *Iulus*; *a*, organ (labrum?) with its palpus, pertaining to the mouth, enlarged. The species

must have burrowed into the interior of the *Sigillaria* trunk in which it was found. (Dawson.)

(*d.*) *Insects.*—Fig. 602 A, *Blattina venusta* Lesquereux, from the Coal measures at Frog Bayou, Arkansas. The specimen is one of the wings; and it very closely resembles the corresponding wing of a modern Cockroach (genus *Blatta*). This is the only insect yet found in the American Carboniferous beds.

5. Vertebrates.—(*a.*) *Fishes.*—Fig. 603 A, *Eurylepis tuberculatus* Newberry; and fig. 603 B, *Cœlacanthus elegans* Newberry,—both Ganoids from the Coal measures at Linton, Ohio. The latter is remarkable for not having the tail heterocercal, although strictly vertebrated. The genus *Eurylepis* of Newberry is a group of small but highly-ornamented fishes, allied to *Palæoniscus*, but distinguished by the high side scales. Other Ganoids occur of the genera *Megalichthys*, *Palæoniscus*, *Amblypterus*, *Pygopterus*, *Rhizodus*, and *Cœlacanthus*, in the Coal measures of the United States and Nova Scotia.

Fig. 603.



GANOIDS.—Fig. 603 A, Eurylepis tuberculatus; 603 B, Cœlacanthus elegans.

Among *Selachians* the following European genera have been recognized in the Coal-measure limestones of Pennsylvania, Ohio, Indiana, Illinois, etc.,—the species being generally distinct from those of the Old World:—1. CESTRACIONTS: genera *Ctenoptychius*, *Petalodus*, *Helodus*, *Cochliodus*, *Pœcilodus*, *Pleuracanthus*, *Ctenacanthus*, and *Oracanthus*. 2. HYBODONTS: genera *Diplodus* and *Cladodus*. (Newberry.)

(*b.*) *Reptiles.*— *Amphibians.*—Fig. 604 A, *Raniceps Lyellii* Wyman, found by Dr. Newberry along with fossil fishes at Linton, Ohio. According to Wyman, it has many of the characteristics of the Batrachians (frogs), or tail-less Amphibians (whence the name, signifying Frog-headed), but appears to be intermediate between that group and the Salamander tribe (tailed Amphibians). No scales have been observed: if possessing them, like the species of Nova Scotia, it would rank among the Labyrinthodonts.

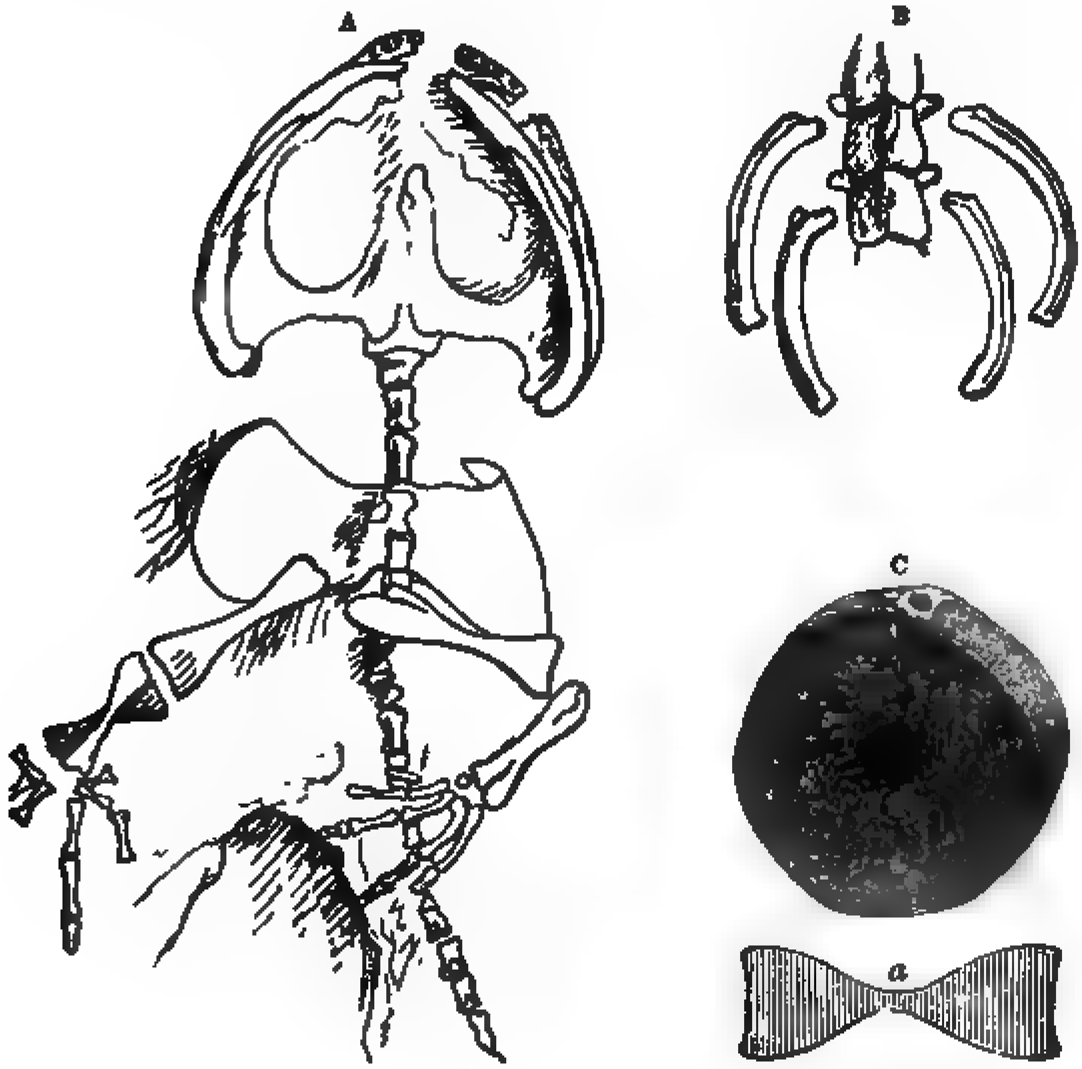
Baphetes planiceps Owen, is the name of an Amphibian from Pictou, Nova Scotia. The specimen is a portion of the skull, seven inches broad,—enough to show the great size of the animal. According to Owen, it was probably a scale-covered and voracious animal of the *Labyrinthodont* tribe.

Dendrerpeton Acadianum is a smaller and narrower reptile from Nova Scotia, and one of the number found in the stump of a *Sigillaria* at the Joggins, as

mentioned on p. 345. It was probably about two and a half feet long; the body was covered with scales, and the whole surface of the cranium was sculptured. Dawson regards it, therefore, as most nearly related to the Labyrinthodonts. The name is from the Greek *δενδρον*, *tree*, and *ερπετον*, *reptile*.

Amphibian footprints have been observed in the Coal measures both of Pennsylvania and Nova Scotia. Near Westmoreland, Pa., in a layer situated about 100 feet below the horizon of the Pittsburg coal, Dr. A. T. King counted twenty-

Fig. 604.



REPTILES.—Fig. A, Raniceps Lyellii; B, Vertebræ and ribs of a Lacertian; C, Vertebra of Eosaurus Acadianus.

three consecutive steps of one individual. Those of the hind-feet are five-toed, and of the fore-feet four-toed,—the former five and a half inches long, and the latter four and a half inches. The distance between the successive tracks is six to eight inches, and between the two lines about the same; which shows that the animal was large, about as long as broad, and probably a Batrachian of the Labyrinthodont tribe. The species is called *Thenaropus heterodactylus*.

Lacertians.—Along with the *Raniceps* were found some of the ribs and vertebræ of two other species of Reptiles, one specimen of which is represented

in fig. 604 B. The existence of ribs separates them from Batrachians, and their length from the Salamandrians; and in this characteristic they approximate to the Lacertians or Lizard tribe among true Reptiles. Dawson has described three species under the generic name *Hylonomus*, which were found with the Dendrerpeton; they have long ribs, as well as scales, and may have been related to the above from Ohio. He regards them as probably Lacertian.

Enaliosaurs.—Two vertebræ of a large swimming Saurian have been found by O. C. Marsh in the Nova Scotia Coal measures, at the Joggins, about 5000 feet below the top of the series. Fig. 604 C represents one of the vertebræ, reduced one-half, and *a*, a transverse section. The resemblance to the vertebra of an *Ichthyosaurus* (see fig. 710) is close. From the depth of its concavities, the animal is supposed to have been one of the most fish-like of the Enaliosaurs. But without more of the skeleton it is difficult to pronounce on its exact relations. The species is named by Marsh *Eosaurus Acadianus*.

COAL MEASURES OF FOREIGN COUNTRIES.

I. Distribution of Coal Regions.

Coal beds of the Carboniferous age are found in Great Britain, France, Belgium, Spain, Germany, Hungary, and China. But it is not yet known that any beds of this age occur in South America, Africa, Australia, or in the whole of southern, central, and western Asia, or in either European or Asiatic Russia. Passing up from Africa and the Orient over Europe, we find the smallest amount of coal in Germany or southeastern Europe; the next in order, in Belgium, France, Spain, Great Britain; or in proportion to the square miles of surface approximately as follows:—France, 1-100th, Spain, 1-50th, Belgium, 1-20th, Great Britain, 1-10th. The number of square miles of coal area in these countries is nearly as follows; that of North America is added for comparison:—

	Square miles.
Belgium	518
France	2,000?
Spain	4,000
Great Britain and Ireland	12,000
British Provinces	18,000
United States	130,000
Total in North America	148,000

The contrast is striking in its bearings on the earth's future, and has a profound historical interest.

Excluding America, Great Britain takes the lead of the rest of the world both in its actual amount of coal and the extent of the coal area as compared with the whole surface. With an area of 120,290 square miles, there are about 12,000 square miles of coal lands. British America, however, in the provinces of New Brunswick, Nova Scotia, Cape Breton, and Newfoundland, stands ahead of her in both respects, its area of 81,113 square miles containing 15,000 or 18,000 square miles of coal land. The State of Pennsylvania leads the world, its area of 43,960 square miles embracing 20,000 of coal land. The Belgian coal fields (a portion of which extends into France) are the most worked among the European.

Russia has a great area of Subcarboniferous rocks, containing some little coal, but only small areas of the Coal measures, in its southern part.

In England (see the following map, in which the black areas are the Carboniferous) the coal regions are situated in a band running north-northeast across from South Wales to the northeast coast, where is the Newcastle basin. The principal regions are the South Wales, 600,000 square acres in area, and, in the same latitude, the region about Bristol, east of the Severn; the small patches in central England, in Worcestershire, Shropshire (Coalbrook Dale), Warwickshire, Leicestershire, and Staffordshire; north of these, the great Lancashire region, which borders on Manchester and Liverpool, with the basin of Flintshire on the Dee, the whole together over 500,000 square acres; a little to the west, the Yorkshire coal region, about Leeds and Sheffield, 650,000 square acres in area; farther north, a patch on the western coast in Cumberland, about Whitehaven, etc.; and on the eastern coast, the great region of Newcastle, 500,000 square acres in area.

In Scotland the beds cover an area of about 2000 square miles, and lie between the Grampian range on the north and the Lammermuirs on the south.

In Ireland there are several large coal regions,—that of Ulster, estimated at 500,000 square acres, of Connaught, 200,000, of Leinster (Kilkenny), 150,000, of Munster, 1,000,000.

The coal workings are carried on in most of the British mines by a regular system of mining. The depth of one of the mines of the Newcastle coal field is 1500 feet; of another 1800; and of those of Yorkshire about 1000 feet. At Whitehaven they reach out far under the sea.

The coal of England, Scotland, and Ireland is mainly bituminous or semi-bituminous. Anthracite occurs in South Wales, especially its western part, and also in the mines of southern Ireland (Cork, Kerry, Limerick, and Clare); but this variety is in general less hard and more inflammable than that of Pennsylvania.

The associated rocks are similar to those of America,—viz., conglomerates, sandstones, shales, limestones, and iron-ore beds; and fire-clays usually underlie each bed. Some deposits are evidently of fresh-water origin, others marine or of brackish-water.

Fig. 605.

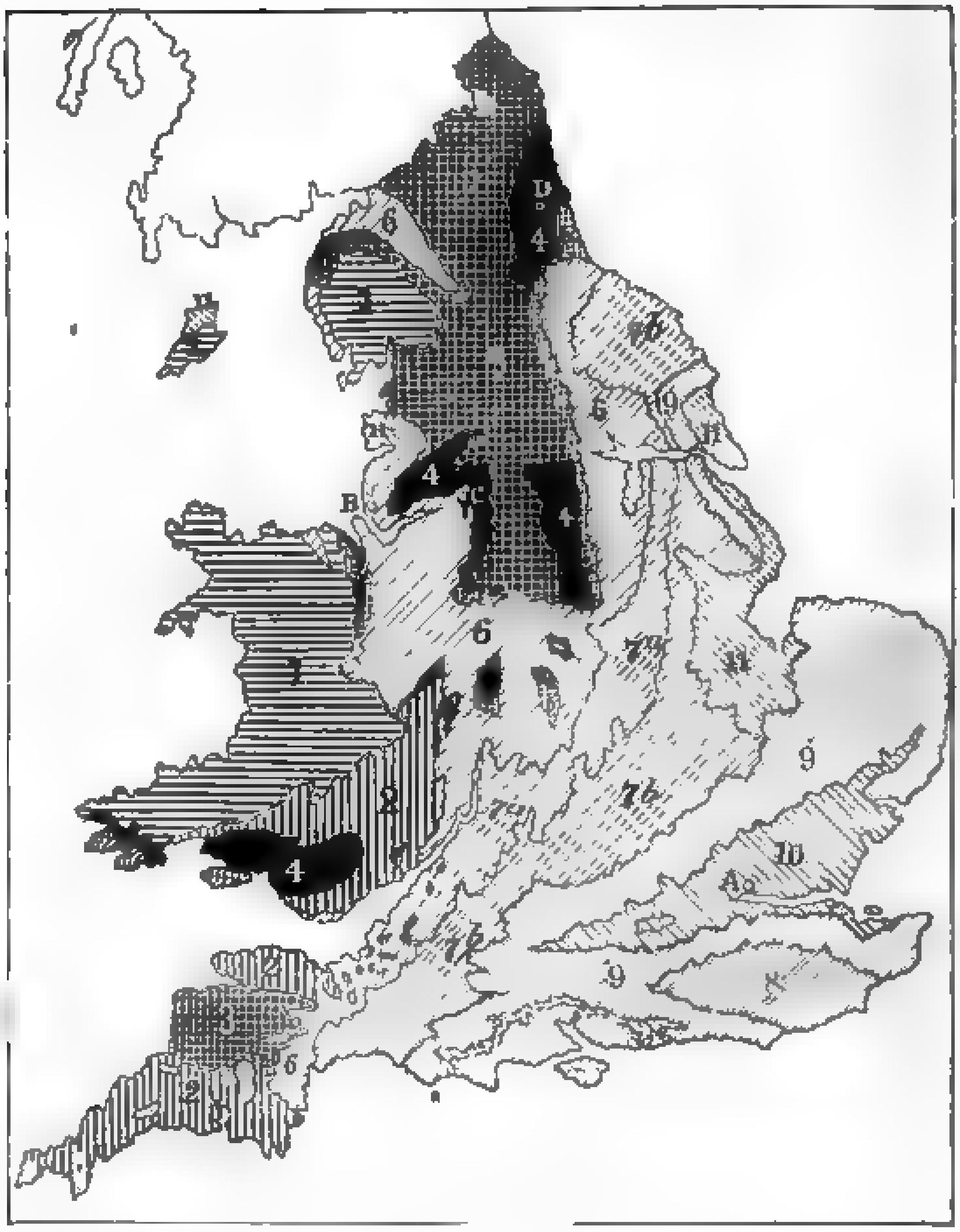


Fig. 605, Geological Map of England. The areas lined horizontally and numbered 1 are Silurian. Those lined vertically (2), Devonian. Those cross-lined (3), Subcarboniferous. Carboniferous (4), black. Permian (5). Those lined obliquely from right to left, Triassic (6), Lias (7 *a*), Oolite (7 *b*), Wealden (8), Cretaceous (9). Those lined obliquely from left to right (10, 11), Tertiary. A is London, B, Liverpool, C, Manchester, D, Newcastle.

The following are the principal coal-mines of the countries of Europe:—

France.—Basin of the Loire (St. Etienne).—Moselle (Saarbrück).—Burgundy.—Languedoc.—Provence.—Limousin.—Auvergne.—Brittany.

BELGIUM.—Liège Coal field,—the eastern division.—Hainault Coal field,—western division.

GERMANY.—Basin of the Saar, tributary to the Moselle on the borders of France.—Basin of the Ruhr, tributary to the Rhine, near Dusseldorf,—the eastern extension of the Belgian region. In Saxony, near Zwickau and Dresden.

AUSTRIA.—Bohemia, south of the Erzgebirge and Riesengebirge, and reaching into Silesia.

SPAIN.—In the Asturias (largest).—Near Cordova.—Catalonia (small).

PORTUGAL.—Near Coimbra.

II. Life.

1. *Plants.*

The same genera are represented among the European coal beds as occur in America; and very many of the species are identical. In this respect the vegetable and animal kingdoms are in strong contrast; for the species of animals common to the two continents have always been few.

The following table, by Lesquereux,* shows the number of American species of the several genera that have also been found in the European Coal measures, as well as the number peculiar to each, America and Europe:—

Genera of Coal Plants.	Species peculiar to America.	Species peculiar to Europe.	Species common to both.
Noeggerathia Sternb.	3	5	1
Cyclopteris Brngt.	1	2	2
Neuropteris Brngt.	21	16	12
Odontopteris Brngt.	6	6	3
Dictyopteris Gutb.	1	1	0
Sphenopteris Brngt.	20	41	12
Hymenophyllites Göpp.	8	10	2
Rhodea Sternb.	0	1	0
Trichomanites Göpp.	0	4	0
Steffensia Göpp.	0	1	0
Beinertia Göpp.	0	1	0
Diplazites Göpp.	0	2	0
Woodwardites Göpp.	0	2	0
Alethopteris Sternb.	12	20	9
Callipteris Brngt.	2	1	1
Pecopteris Brngt.	16	49	12
Aphlebia Sternb.	0	6	1
Caulopteris Brngt.	4	4	0
Psaronius Brngt.	10	6	0
Crematopteris Schp.	1	0	0

* Am. Jour. Sci. [2] xxx. 66. In the table, as originally published by Lesquereux, the species of Dr. Newberry's cabinet are added with an asterisk: the above has been modified upon advice received from the latter. The identification of American with European species requires more careful investigation, as Lesquereux and Newberry both observe.

Genera of Coal Plants.	Species peculiar to America.	Species peculiar to Europe.	Species common to both.
Scolopendrites Lsqx.	1	0	0
Whittleseya Newb.	1	0	0
Cordaites Ung.	1	0	2
Diplotegium Corda	0	0	1
Stigmaria Brngt.	5	2	5
Sigillaria Brngt.	21	37	17
Syringodendron Brngt.	2	2	2
Diploxylon Corda	0	0	1
Lepidodendron Brngt.	14	10	11
Ulodendron Rhode	0	4	2
Megaphytum Artis	2	4	0
Knorria Sternb.	2	1	2
Halonia Ll. & Hutt	0	2	1
Lepidophyllum Brngt.	7	2	4
Lepidostrobus Brngt.	1	1	2
Cardiocarpum Brngt.	7	6	2
Trigonocarpum Brngt.	6	5	5
Rhabdocarpus Göpp. & Brngt.	2	6	1
Carpolithes Sternb.	12	52	6
Selaginites Brngt.	0	1	0
Lycopodites Brngt.	1	12	0
Lepidophloios Sternb.	1	0	1
Bothrodendron Göpp.	0	1	0
Calamites Suck.	2	5	11
Bornia Sternb. & Göpp.	1	1	0
Asterophyllites Brngt.	5	8	7
Annularia Sternb.	1	0	5
Sphenophyllum Brngt.	5	3	3

According to this table—which was prepared in 1860—there are in all about 350 known American species, and 490 European (and British); and of these 146 are common to the two continents. In other words, more than *one-third* of all the American species were growing also in the Carboniferous forests of the other continent.

2. *Animals.*

The most important additions to the facts already stated, furnished by the European rocks, are those relating to the class of Insects and Spiders. We learn that besides *Cockroaches*, which also existed in Europe, there were probably *Weevils*, as well as other kinds of beetles, species related to the *Dragon-fly*, and also *Termites* and *Locusts*. The class of Spiders (or Arachnidæ) was represented by *Scorpions* and Pseudo-scorpions.

The Vertebrates were similar in type to the American, the fishes being *Ganoids* and *Selachians*, and the Reptiles *Labyrinthodonts* and other Amphibians.

A review of the species of *Radiates* and *Mollusks* is not necessary here, as the facts add nothing new in principle to what has been gathered from the American strata.

The remains of marine species are not common in the Coal measures of Europe or of Britain, while those of the American coal fields are almost all marine.

Figs. 606–610.

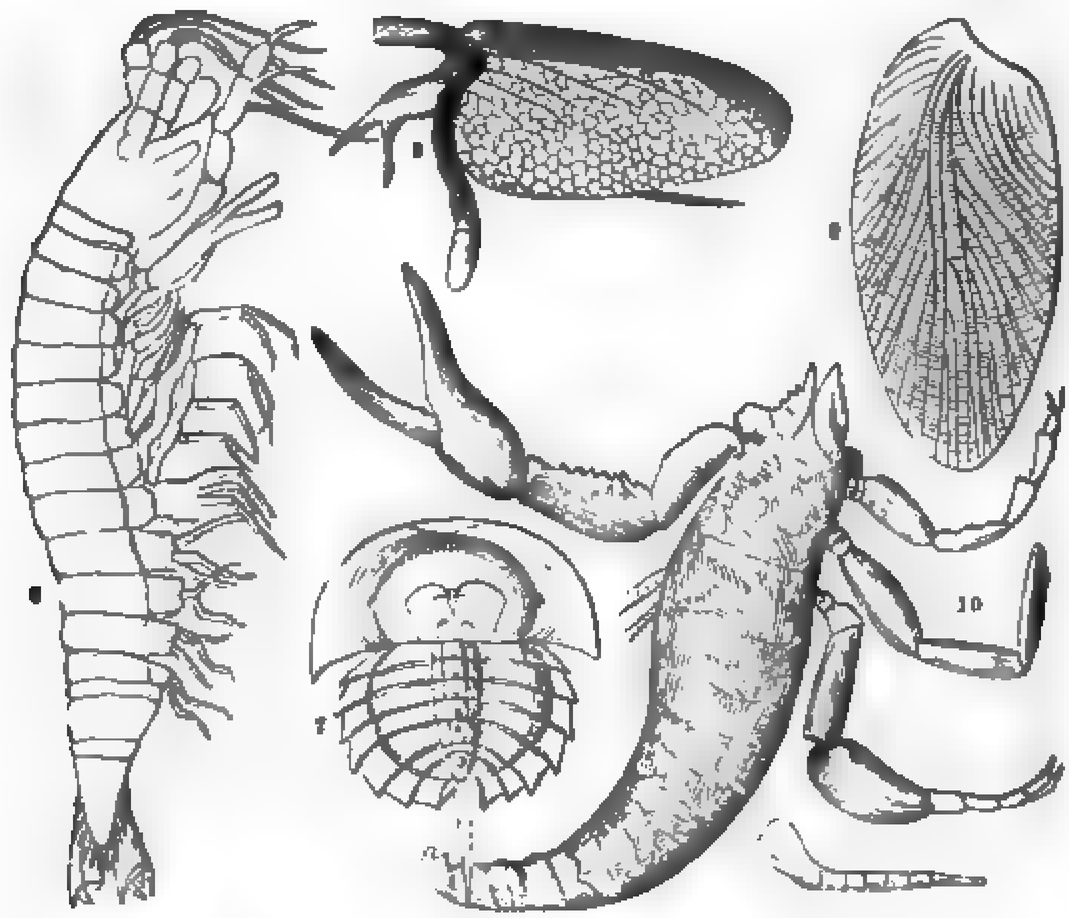
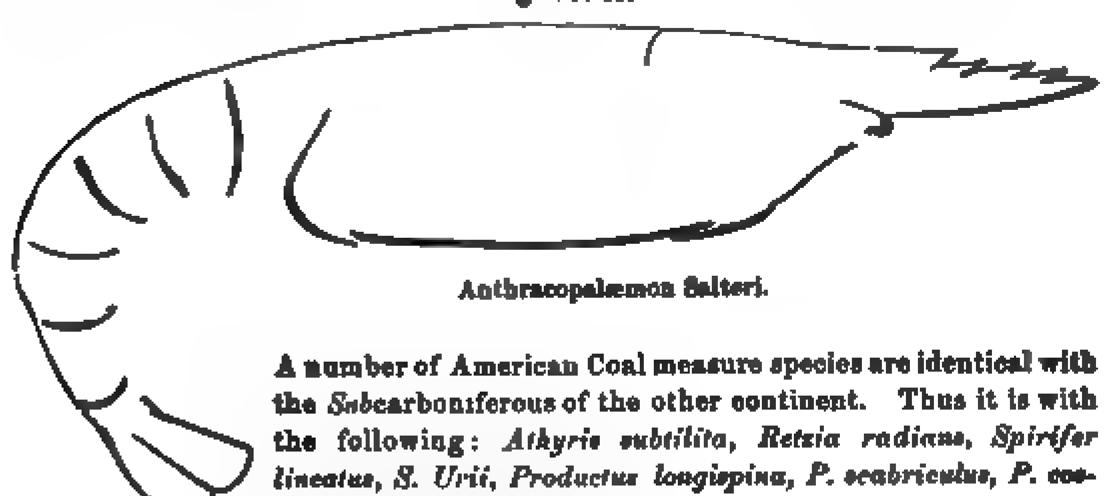


Fig. 606, Gampsonyx fimbriatus; 607, Bellinurus (Limulus) rotundatus (× ½); 608, Dictyoneura anthracophila; 609, Blattina primæva; 610, Cyclophthalmus Bucklandi.

Fig. 610 A.



Anthracopalæmon Salteri.

A number of American Coal measure species are identical with the *Sub*carboniferous of the other continent. Thus it is with the following: *Athyris subtilita*, *Retzia radians*, *Spirifer lineatus*, *S. Urii*, *Productus longispina*, *P. scabriculus*, *P. costatus*, *Fusulina cylindrica*.

1. **Articulates.**—(*a.*) *Crustaceans.*—No species of Trilobites are reported from the foreign Coal measures,—showing, apparently, the complete extinction

of this ancient tribe. But there were Crustaceans of new kinds. Fig. 607, *Belli-nurus* (*Limulus*) *rotundatus*, reduced one-half, a species related apparently to the Horseshoe (*Limulus*) of the Atlantic coast. Fig. 606, *Gampsonyx fimbriatus*, like a shrimp in general form, but belonging to the tribe of *Schizopods*, that is, Macrourans having an accessory branch to the legs (from σχίζω, *to divide*, and ποῦς, *foot*); they are the lowest of Macrourans (p. 153). Fig. 611 A represents a species still more like a shrimp, and it has been called *Anthracopalæmon*, from *Palæmon*, the name of a modern genus of shrimps, and the Greek for *coal*. It is from Lanarkshire, Scotland. *A. dubius* and *A. Grossarti* are other species referred to this genus, the former from Coalbrook Dale (includes the *Glyphea? dubia* Salter, and *Apus dubius* M. Edwards), and the latter from Lanarkshire; but the broad flattened carapax indicates a nearer relation to *Æglea* and *Galathea* than to *Palæmon*. *Pygocephalus Couperi* is the name of a Schizopod from near Manchester, England.

(*b.*) *Spiders.*—Fig. 610, *Cyclophthalmus Bucklandi*, a scorpion of the Coal measures of Chomle, in Bohemia. *Microlabis* is another Carboniferous genus, of the family of Pseudo-scorpions. These are the first of the class of Spiders in geological history.

(*c.*) *Insects.*—Remains of insects have been found at several localities, and especially at Saarbrück and Wettin. Fig. 609, a wing of the *Blattina primæva* Jordan, or Carboniferous Cockroach, very similar to the American (fig. 602 A); it is from Saarbrück. Fig. 608, wing of *Dictyoneura anthracophila* Jordan, a Neuropterous insect of the Semblis family. Saarbrück has afforded also a species of *Termites*, another Neuropterous insect; a *locust* (Orthopterous) for which the genus *Gryllacris* has been instituted; and a *beetle* or Coleopter referred to the new genus *Traxites*. Two *weevils* (Curculionids) have been reported from Coalbrook Dale (Shropshire), England; but Heer regards them as Crustaceans, and not Insects.

Vertebrates.—(*a.*) *Fishes.*—The fishes of the Carboniferous age are found most abundantly in the Subcarboniferous limestones, as these were wholly of marine origin: still, a considerable number of species occur in the Coal measures. The Selachians are of the genera *Ctenodus*, *Ctenoptychius*, *Gyracanthus*, etc., and also *Helodus*, *Cladodus*, *Orodus*, *Ctenacanthus*, etc., which are mostly Subcarboniferous. The most common Coal measure genera of Ganoids are *Palæoniscus*, *Amblypterus*, and *Holoptychius*. All the Ganoids have vertebrated tails.

(*b.*) *Reptiles.*—A few Reptilian remains have been observed in Europe and Britain similar in general character to those of America, and indicating the existence of ordinary Amphibians and Labyrinthodonts. One species, *Parabatrachus Colei* Owen, is a Labyrinthodont from the British Coal measures. The *Archegosaurus Decheni* Goldfuss, a Carboniferous species from Saarbrück, has been regarded as a Proteoid Salamandrian. But Agassiz has observed that even in their limbs—their most Reptilian feature—they are closely like Ganoid fishes of the genus Polypterus. *Apateon pedestris* H. v. Meyer, is another species related to the Archegosaurus, if not of the same genus; it is from near Münsterappel, on the Bavarian Rhine.

General Observations.

1. Origin of Coal.—(1.) *Coal derived from Vegetation.*—As the coal beds and accompanying strata abound in the impressions of leaves and stems, and the coal also consists of vegetable fibres (p. 328), the vegetable origin of coal is beyond all reasonable doubt.

(2.) *Plants of the Coal.*—The plants that have contributed most to the formation of the great beds of vegetable debris which were afterwards converted into coal, are the *Sigillarids*, the *Calamites*, and the *Conifers*, with the *Lepidodendra* for that of the Lower Coal measures. The *Conifers* and *Lepidodendra* probably spread also over the dry land covering the plains and hills, while the *Sigillarids* and *Calamites* were mainly plants of the great marshes. Along with these were numerous herbaceous ferns, but rarely tree-ferns: even the stems of the small ferns are not common in the coal itself, though abundant in the accompanying shales.

(3.) *The plants either land or fresh-water species.*—That the plants were not such as frequent salt marshes, but, on the contrary, those of the land or fresh-water marshes, is obvious from (1) the nature of the plants themselves; (2) the absence of sea-weeds from among the species of the coal beds; (3) the presence of the remains of insects. It is not possible that some of the beds have originated from the vegetation of salt marshes and others from that of the land or fresh-water marshes, because there is a great uniformity in the plants of the several beds,—showing that all are of one mode of growth and origin.

(4.) *Coal a result of the decomposition of plants.*—Mineral coal is simply the element *carbon* along with some kinds of bituminous substances that consist of carbon and hydrogen, and also admixtures, small or large, of earthy impurities.

Dry vegetable matter consists of about 49 per cent. of carbon, 6.3 of hydrogen, and 44.6 of oxygen. The first, the essential element of the coal, is solid at the ordinary temperature; the other two elements are gases. In the decomposition of wood, the gaseous part escapes, carrying off part of the carbon in combination with it, and leaves the rest of the carbon as coal, with more or less bitumen, derived from a union of some carbon and hydrogen. In this decomposition, the oxygen may combine (1) with part of the hydrogen to form water; (2) with part of the carbon to form carbonic acid or carbonic oxyd; also the hydrogen may combine with the oxygen of the atmosphere to form water; or some of it with some of the carbon to produce carburetted hydrogen gas, or (with or without oxygen) the bituminous substances. By these means, half or more of the

carbon of the wood is lost as gas, and nearly all the gaseous ingredients besides. It has been estimated by Bischof that 100 parts of wood will not make more than 16 parts of anthracite and 25 of bituminous coal.

Bischof states the conditions and changes as follow:—

Ultimate constitution of wood, anthracite, bituminous coal, and asphaltum,—impurities excluded:—

	Wood.	Anthracite.	Bituminous coal.	Asphaltum.
Carbon	49.1	94.04	82.2	81.6
Hydrogen	6.3	1.75	5.5	9.6
Oxygen	44.6	4.21	12.3	8.8

If the escaping gases in decomposition are *carbonic acid* and *carburetted hydrogen*, the loss of each element for anthracite and bituminous coal would be as follows:—

	For Anthracite.				For Bituminous Coal.		
	Wood.	Loss.	Coal left.	Coal left. in p. c.	Loss.	Coal left.	Coal left in per cent.
Carbon	49.1	34.57	14.53	94.04	31.0	18.1	82.2
Hydrogen.	6.3	6.03	0.27	1.75	5.1	1.2	5.5
Oxygen	44.6	43.95	0.65	4.21	41.9	2.7	12.3
	100.0	84.55	15.45	100.00	78.0	22.0	100.0

The loss for the anthracite is 60.79 per cent. of carbonic acid, and 24.12 of carburetted hydrogen.

If the escaping gases were *carbonic acid* and *hydrogen*, the last forming water with external oxygen, the whole loss in a similar manner would be—for anthracite 65 per cent., leaving 35 of coal; and for bituminous coal 58¼ per cent., leaving 41¾ of coal.

If, again, the part lost is *carbonic acid* and *water*, both derived from the elements of the wood, the amount of coal left in case of bituminous coal would be about 54½ per cent.

There is, therefore, a loss of three-fourths of the wood in the case of bituminous coal, and five-sixths in that of anthracite. Besides this reduction to one-fourth and one-sixth by decomposition, there is a reduction in bulk by compression; which if only to one-half would make the whole reduction of bulk to one-eighth or one-twelfth. Consequently, it would take eight feet in depth of compact vegetable debris to make one foot of bituminous coal, and twelve feet to make one of anthracite. For a bed of pure anthracite 30 feet thick, like that at Wilkesbarre, the bed of vegetation must have been at least 360 feet thick, or, allowing for impurities, over 300 feet.

(5.) *Impurities of the coal.*—The impurities of the coal are in part derived from the wood. *Silica* is contained in the exterior part of

rushes and many other plants; and this would remain in the coal. *Potash* is present in all vegetation; but, as its salts are soluble, it would mainly disappear in the course of the decomposition. Traces of sulphur occur in all vegetable matters as well as animal, whether microscopic or not, which might, therefore, be present in the accumulating beds; and this *sulphur*, by combination with iron, would have formed *pyrites*,—a common impurity in coal beds.

Impurities were also introduced as earth or clay. Even the winds transport dust, and the waters carry detritus. Both of these means may have contributed to the earthy ingredients of the coal.

Waters may also bring in other ingredients *in solution*, as oxyd of iron in combination either with carbonic acid, sulphuric acid, or some organic acid; for iron is carried in these ways (mainly the last) into all marshy or low regions from the hills around, being derived from the decomposition of *pyrites* (a sulphuret of iron) and other iron minerals.

Sulphate of iron would lose its oxygen from contact with decomposing vegetation, and become sulphuret of iron or pyrites; and this is another source of pyrites. In the change, the oxygen takes carbon from the coal or decomposing plants, and forms carbonic acid, which passes off into the air, and leaves only sulphur and iron, to make sulphuret of iron, or pyrites.

(6.) *Coal-making decomposition takes place only under water.*—Where vegetation decomposes in the open air, all the carbon enters into gaseous combinations, and is lost in the atmosphere, only traces remaining to give a dark color to the soil. Hence forests may, with each autumn, drop tons of solid material to the ground, age after age, and yet little remain behind to indicate the existence of that vegetation. But where the bed of leaves and other relics of the plants is covered by water, so that the air is mostly excluded, the decomposition is less complete,—precisely as when wood is charred in a half-smothered fire; a part of the carbon remains behind, and forms coal. These principles are sustained by facts in all parts of the world. Hence, if a continent were spread equally with vegetation from the equator to the poles, it would form and preserve beds of vegetable debris and fossils only in its marshy regions, or where the relics had been swept off into the waters and had there become buried.

2. **Climate, Atmosphere.**—The growth of the Carboniferous vegetation was dependent, as now, on the climate and the condition of the atmosphere.

(1.) *Temperature of the ocean and air.*—In the animal life of the waters we have a safe criterion for the temperature of the oceans.

Among the species there was the large coral *Lithostrotion basaltiforme*, common in both Europe and the United States. One such species is almost sufficient to prove a similar temperature for the ocean over these three distant regions. This *Lithostrotion* was found by Beechey on the northwest Arctic coast, between Point Barrow and Kotzebue Sound; and with it occurred other corals, and among the Brachiopods *Productus Martini*, well known in lower latitudes. The Arctic was, therefore, at that time a reef-growing sea; and if the distribution of corals, forming coral-reefs, was limited by the same temperature then as now, the waters were at no part of the year below 66° F. Besides the above species, there have been identified in the Arctic, the European species *Productus sulcatus*, *Atrypa aspera*, *A. fallax:* these were found on Bathurst and the neighboring islands, in latitudes 75° and 77°.

The small diversity in the oceanic temperature of the globe is further shown by the occurrence of the following Carboniferous species in the Bolivian Andes:—*Productus semireticulatus*, *P. longispinus* Sow., *Athyris subtilita* Hall, and a *Bellerophon* resembling *B. Urii* Fleming.

The coal beds of the Arctic are evidence of a profuse growth of vegetation over an extended area and protracted through a long period. The conditions between the latitudes 70° and 78° were, therefore, analogous to those over the United States from Pennsylvania to Alabama and from Illinois to Texas. While a general resemblance to the ancient flora of the United States and Europe is apparent from the observations which have been made, particular species have not yet been identified. The plants were not mosses of peat swamps, such as now extend far north. If we draw any conclusion from the facts, it must be that the temperature of the Arctic differed but little from that of Europe and America. Through the whole hemisphere—and, we may say, world—there was a genial atmosphere for one uniform type of vegetation, and there were genial waters for Corals and Brachiopods.

(2.) *Moisture of the atmosphere.*—A warm state of the globe would necessarily imply a very much larger amount of evaporation than now. The climate would be insular throughout, and heavy mists would rest over the land, making the air and land moist. The comparatively small diversity of climate between the equator and poles would probably be attended with fewer storms than now, and a less rapid movement in the general circulation.

(3.) *Impurity of the atmosphere.*—In the present era, the atmosphere consists essentially of oxygen and nitrogen, in the proportion of 23 to 77 parts by volume. Along with these constituents there are about 4 parts by volume of carbonic acid in 10,000 parts of air. More

carbonic acid would be injurious to animal life. To vegetable life, on the contrary, it would be, within certain limits, promotive of growth; for plants live mainly by means of the carbonic acid they receive through their leaves. The carbon they contain comes principally from the air.

This being so, it follows, as has been well argued, that the carbon which is now coal, and was once in plants of different kinds, has come from the atmosphere, and therefore the atmosphere now contains less carbonic acid than it did at the beginning of the Carboniferous, by the amount stowed away in the coal of the globe.

Such an atmosphere, containing an excess of carbonic acid as well as of moisture, would have greater density than the present: consequently, it would (1) have increased heat at the earth's surface, and this would be the cause of a higher temperature over the globe than the present. (E. B. Hunt.) This density would (2) tend to diminish the rate of movement in the atmospheric circulation, and the frequency of storms or violent disturbances.

During the progress of the Carboniferous period, there was, then, (1) a using up and storing away of the carbon of the superfluous carbonic acid, and, thereby, (2) a more or less perfect purification of the atmosphere and diminution of its density. In earlier time there had been no aerial animal life on the earth; and as late as the Carboniferous period there were only reptiles, insects, and pulmonate mollusks. The cold-blooded reptiles, of low order of vital activity, correspond with these conditions of the atmosphere. The after-ages show an increasing elevation of grade and variety in the living species of the land.

(4.) *Influence of the climate on the growth of plants.*—A moist warm climate produces exuberant growth in plants that are fitted for it. The plants of the Coal period were made for the period. The *Sigillariæ* and *Calamites* manifest, by their characters and mode of occurrence, that they could flourish only in a moist region; and the ferns of the tropics, as well as Equiseta everywhere else, like moist woods. The *Lepidodendra*, by their association with the *Sigillariæ* and *Ferns*, show that the same conditions (as is now the case with their kin the Lycopodia) favored their development. In fact, Lycopodia, Equiseta, and most ferns, are plants that like shady as well as moist places. Adding, then, the prevalent moisture and warmth to the excess of carbonic acid in the atmosphere, we should be warranted in concluding that, even if there was less sunshine than at the present time, vegetable growth must have been more exuberant than now, especially in our colder temperate zones. This exuberance would not have shown itself in thick rings of growth

in trees, made for those very conditions, but, as through the existing tropics, under a moist climate, in the great denseness of the jungles and forests, many plants starting up where but one would have flourished under less favorable circumstances. Our peat swamps are often referred to as a measure for the growth of plants in the Coal era. But this is an assumption not based on a due consideration of the facts. The peat plants of the present day are species of the temperate zone alone, and are too different in kind to warrant a comparison.

3. **General Geography of North America.**—The Subcarboniferous period was a time mainly of *submerged* continents; the Carboniferous, of general *emergence*. The conglomerate (Millstone grit), with whose formation the Coal period began, marks the transition from the marine to the land period.

(1.) *Epoch of the Millstone grit.*—The areas overgrown by Crinoids became in the Millstone epoch covered to a great extent by pebbles and sand. These coarse beds indicate strong currents or heavy breakers; and such would sweep the surface during an epoch of slow emergence. The great thickness and coarseness of the beds through Pennsylvania, along the Appalachian region, point out that this was the border reef of the continent and the region of great subsidences. The more sandy character of the beds of this border in Virginia harmonizes with the general fact in earlier time; and so also do the little thickness and finer character of the beds of Ohio and eastern Kentucky,—a region on the inner margin only of the subsiding Appalachian area, not participating in the great change of level.

The coal beds, in this epoch of the Millstone grit, also show that the continent was in this semi-emerged condition; for every such bed is proof that areas of land were here and there above the ocean, where plants could grow.

(2.) *Epoch of the Coal Measures.*—As the plants were land-plants, and the beds cover a vast area stretching almost continuously from the middle or eastern border of the Appalachian region to the farther limits of Missouri and Kansas, this great continental region is safely regarded as at times beyond the reach of the ocean. The emergence, going on in the Millstone-grit epoch by slow steps of progress, ended, therefore, in a great increase of the continental lands. They not only extended from the remote Arctic down to southern New York, but they spread west and south,—west beyond Missouri, and south over Tennessee and part of Alabama. Farther west, there were limestones of the Coal Measure epoch forming, instead of coal; and these indicate that the old interior sea still

covered the slopes and summits of the Rocky Mountains, and over these meridians the waters may have connected with the Arctic Ocean. The limestones of Point Barrow, at the farther extremity of the Rocky Mountain range, may be of the same age.

As single coal beds in the earlier part of the series appear to have had a very wide range, it is safe to conclude that the great central coal area stood nearly at a common level,—that the region was a vast plain, with, at the most, only gentle undulations in the surface breaking its continuity, and with the higher land mainly over the Azoic and Silurian lands to the north. There were no Appalachians, for this very region was a part of the great coal-making plain; there were no Rocky Mountains, for these, as the Carboniferous limestones prove, were mainly under the sea.

Being thus level, there could have been no great Mississippis, and no sufficient drainage for the continent; and the wide plains would have necessarily been marshy, and spotted with shallow lakes.

Eastward there was another similar level area, in Rhode Island and eastern Massachusetts, which probably extended northwestward over the Nova Scotia Coal field to the interior of Newfoundland, covering more or less of Massachusetts Bay, eastern Maine, Nova Scotia, New Brunswick, and the Gulf of St. Lawrence. The continent in that direction, therefore, had for the time its present enlarged limits, and probably spread even beyond. Near the present mouth of the St. Lawrence must have emptied the principal river of the continent; for in the back country at that era there were mountains of moderate elevation, to pour waters into such a stream,—the Azoic heights of northern New York and Canada.

Over these marshes, then, grew the clumsy *Sigillariæ* and *Calamites*, and the more graceful *Lepidodendra* and *Conifers*, with an undergrowth of ferns, and upon the dry slopes near by, forests of *Lepidodendra* and *Conifers;* and the luxuriant growth was prolonged until the creeping centuries had piled up vegetable debris enough for a coal bed. Trees and shrubs were expanding, and shedding their leaves and fruit, and dying, making the accumulation of vegetable remains. Islands of vegetation, like those now occurring in India, may have floated over the lakes and contributed to the vegetable debris. Stumps stood and decayed in the swamps, while the debris of the growing vegetation, or detritus borne by the waters, accumulated around them, and their hollow interiors received sands, or leaves, or bones, or became the haunts of reptiles, as was their chance.

Where the floating islands and other vegetation were drifted out into salt-water bays, the coal-bed accumulations might contain

marine shells,—a fact observed in more than one case in the coal of the United States.

As already explained, there is no reason to suppose that the vegetation was confined to the lower lands: it probably spread over the whole continent, to its most northern limits. It formed coal only where there were marshes, or the deposits of vegetable debris became covered by water-deposits of sand, clay, or other rock-material.

4. **Phases in the progressing Carboniferous period.**—The condition of the continent which has been described represents only one phase in the Carboniferous period. The rocks register a succession of changes; for coal beds are succeeded by sandstones, or shales, or limestones, or iron-ore beds, and many alternations of these beds, to a thickness fifty times as great as that of the coal beds. These intervening strata, moreover, may be fresh-water or marine: in the one case, with fresh-water shells or other inland species; in the other, full of Crinoids and Brachiopods, the life of the sea. The great extent of the continent, wherever these strata occur, underwent, therefore, continued oscillations of level, or the sea as unceasing changes of water-level. After a period of verdure there followed a desolation as complete as that when the lower Millstone grit was spread over the surface,—either a subsidence of the interior, or some other change that led to a general submergence beneath fresh waters, or a movement or removal or sinking of barriers, that placed the whole beneath salt water: in either case, the former vegetation gave way to the water-life again, and the broken relics are often packed together in the first deposits that ensued. The oscillations must have been exceedingly various to have produced all the alternations of shales, sandstones, limestones, and ore-beds. They must have been also slow in progress: motion by the few inches a century accords best with the facts. The continent may have rested long near the water's surface, just swept by the waves. It may have been long a region of barren marshes; and in this condition it might have received its iron-ore deposits, as now marshes become occupied by bog-ores. It must have been long in somewhat deeper waters, and covered with a luxuriance of marine life. Finally, the land escaped again from the waters, and the old vegetation spread rapidly across the great flats, commencing a new era of coal-making vegetable debris; or the escape was only partial, and coal-plants took possession of one part and made limited coal deposits, while the sea still held the rest beneath it; for uniform oscillations of level in all cases through so great an area are not probable, and therefore the former continuity of a single coal bed through the East and West requires strong proof to be admitted.

Should a general submergence be proved, it remains a question whether the lowering of the sea-level on the land was due to a rising of the land, or a deepening of the ocean's bed causing a withdrawal of the waters; for the ocean's bed has ever been as liable to oscillations as the continental part of the crust, and the effects should have been as much greater than those from the oscillating land as the area of the ocean is greater. Whichever be the mode, the movements would generally have been such as would become appreciable only by the lapse of many years or a century.

In Nova Scotia these changes went on until 14,570 feet of deposits were formed; and in that space, as has been stated, there are 76 coal seams and dirt-beds, indicating as many levels of verdant fields between the others when the waters prevailed. In Pennsylvania there are nearly 3000 feet of rocks in the series, and 60 to 120 feet of coal.

The coal beds are thin, compared with the associated rocks. But the time of their accumulation, or the length of all the periods of verdure together, may have far exceeded the time that was given up to the accumulation of sands and limestones. If there were but 100 feet of coal in all, it would correspond to between 500 and 1000 feet in depth of vegetable debris. The sands and clays came in after each time of verdure to store away the product for a future age.

In the Nova Scotia Coal measures there is evidence in the fossils that the waters in which were accumulated the rocky layers that intervene between the coal beds were, to a large extent, fresh or brackish. The occurrence of a *Spirorbis* along with the Pupa and Reptilian remains in the Sigillaria stump has been considered as evidence in this particular case of the presence of brackish water during the burial of the stump. There are but few beds in the whole thickness of the Nova Scotia Coal formation that contain marine fossils. The land-snail (Pupa) occurs in another bed—an under-clay—over 1200 feet below the level of the stump in which it was first found; and in this interval there are twenty-one coal seams, showing, as Dawson observes, that the species existed during the growth and burial of at least twenty forests. It proves the terrestrial character of the coal vegetation.

In the Interior Continental region, the submergence attending the formation of these intervening rocks was mostly or wholly marine; for all the fossils thus far observed are those of marine species, and they occur in many strata of limestone, sandstone, and shale throughout the Coal measures. Over the great Mammoth bed of Wilkesbarre there are shales (at the township of Hanover) con-

taining marine shells. The thinner shales among the coal beds and limited arenaceous layers may, however, have been formed when the marshes became flooded with fresh waters; while the great sandstones and limestones and thicker shales are all evidence that the former fresh-water marsh was followed, through submergence, by a flood of marine waters. The extermination of the Lepidodendra of the Lower Coal measures was probably connected with such a submergence.

The Lower Coal measures extend to the most eastern limits of the anthracite in Pennsylvania, and contain but little limestone either in the east or west. The Upper, above the Pittsburg bed, reach east only over the western portion of that State. This more western limit shows plainly a rising of the country more to the east to a height that was too dry for the marsh-vegetation of which coal was made. We observe, further, that limestones are common in the Upper Coal measures, and they increase much going westward; and finally, as has been stated, they prevail extensively over the larger part of the Rocky Mountain region.

The coal bed itself bears evidences of alternations of condition in its own lamination, or even in the alternations in its shades of color. A layer an eighth of an inch thick corresponds to an inch at least of the accumulating vegetable remains; and hence the regularity and delicacy of the structure are not surprising. Alternations are a consequence of (1) the periodicity in the growth of plants and the shedding of leaves; (2) the periodicity of the seasons, the alternations of the season of floods with the season of low waters or comparative dryness; (3) the occurrence, at intervals of several years, of excessive floods. Floods may bring in more or less detritus, besides influencing the fall and distribution of the vegetation. In some conditions, there would be a long steeping of the vegetation in the waters before it was put under the pressure of beds of clay or sand; and the precise quality of the coal would be varied thereby, the decomposition of the vegetation depending on the amount of water, the composition of that water, and the length of time exposed. Newberry has suggested that bituminous coal has taken the form of Cannel when the vegetation was reduced to a perfect pulp at the time of the change to coal.

Conclusion.—The Coal period was, then, a time of unceasing change,—eras of universal verdure alternating with others of wide-spread and destructive waters, destructive of all the vegetation and land-life except that which covered regions beyond the Coal-measure limits. According to the reading of the records, it was a time of great forests and jungles, and of magnificent foliage, but of few or inconspicuous flowers; of Acrogens and Conifers, with no Angiosperms; of marsh-loving insects, Myriapods and Scorpions as well as Crustaceans and Worms, representatives of all the classes of Articulates, but not the higher insects that live among flowers; of the

last of the Trilobites, and the passing climax of the Brachiopods and Crinoids; of Ganoids and Sharks, but no Teliosts or Osseous Fishes, that make up the greater part of the modern tribes; of Amphibians and some inferior species of True Reptiles, but no Birds or Mammals; and therefore there was no music in the groves, save, perhaps, that of insect life and the croaking Batrachian. Thus far had the world progressed by the close of the Carboniferous period.

The special history of the Coal period of Europe and Britain might be followed out, as has been done for North America. But it would illustrate no new principles, and would be more appropriate in a general treatise than in a text-book. More facts are to be ascertained, before the details of the history are as clearly deciphered.

3. PERMIAN PERIOD (15).

The Permian period, the closing era of the Carboniferous age, was a time of decline for Palæozoic life, and of transition towards a new phase in geological history.

The term *Permian* was given to the rocks of the period by Murchison: it alludes to the district of Perm, in Russia, which is characterized by this formation.

No division of the Permian period in America into epochs has been recognized.

1. AMERICAN.

I. Rocks: kinds and distribution.

The Permian rocks are confined to the *Interior Continental basin*, and occur in the portion of it west of the Mississippi,—especially in Kansas, and some parts of the eastern slope of the Rocky Mountains. They overlie conformably the Carboniferous; and, as the rocks make one continuous series, it is difficult to determine the limit between the two formations.

In Nebraska and Kansas, they outcrop along the western border of the Carboniferous region, in a strip running from Nebraska City southward (or a little west-of-south), and also in patches to the east of this range. On the map, p. 133, the Permian is distinguished by light dots on a dark ground. The beds occur also about the Black Hills (near lat. 44° N. and long. 104° W.), on the eastern slope of the Big Horn Mountains, and, according to Shumard, in the Guadalupe Mountains in New Mexico.

The rocks are limestones, sandstones, red, greenish, and gray marls or shales, gypsum beds, and conglomerates, among which the limestones in some regions predominate.

The whole thickness made out by Swallow & Hawn is about 820 feet, and of this 263 feet are called the *Upper* Permian, and the rest the *Lower*. Meek & Hayden refer the Lower division, with good reason, and also a part of the Upper, to the Upper Coal measures. The limestones are usually impure, and also magnesian, like most of the limestones of the same region of older date. They are generally rather soft or irregular in structure, and much interlaminated with clayey or arenaceous beds; some of the layers contain hornstone.

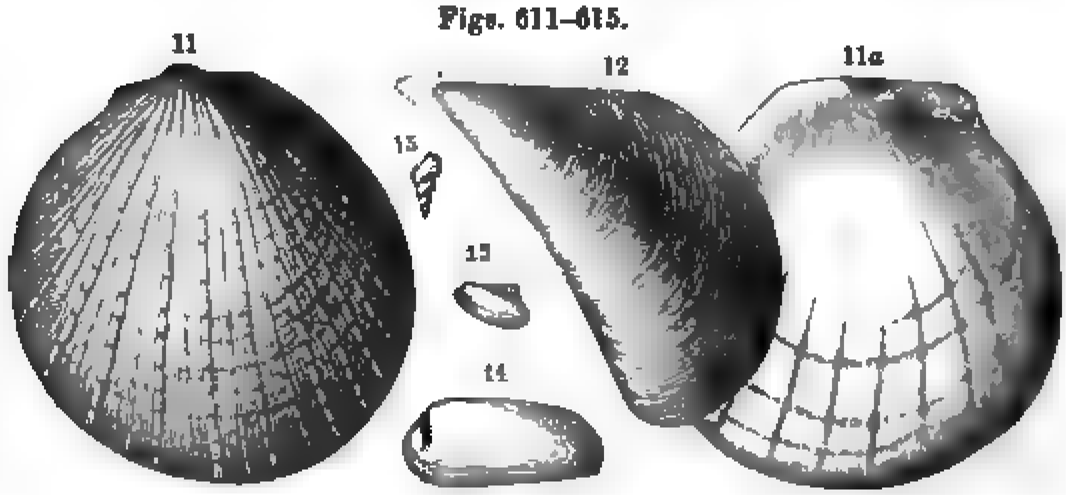
II. Life.

Nothing is yet known respecting the American Permian flora.

Allowing the Permian the widest range attributed to it, the animal species are rather numerous; but they include many Carboniferous forms, and among them *Crinoids*, an *Archæocidaris*, and a Trilobite of the genus *Phillipsia*, besides Mollusks. But, restricting the period only to the upper strata, which are recognized by all investigators as Permian, there are only a few Mollusks.

The species here figured occur in the uppermost beds (Permian of Meek & Hayden). Fig. 611, *Monotis Hawni* M. & H., cast of the outside of the left valve; 611 *a*, cast of the interior of the right valve of the same. The genus *Monotis* is related to *Avicula*: it has an opening below the beak for the passage of the byssus, as shown in the figure. Fig. 612, *Myalina perattenuata* M. & H.; fig. 613, *Bakewellia parva*; fig. 614, *Pleurophorus subcuneatus* M. & H.; fig. 615, shell of a small undetermined *Gasteropod.*

Figs. 611–615.



MOLLUSKS.—Figs. 611, 611 *a*, Monotis Hawni; 612, Myalina perattenuata; 613, Bakewellia parva; 614, Pleurophorus subcuneatus; 615, an undetermined Gasteropod.

Among the species of Mollusks from the beds referred to the Permian by Swallow, 75 in number, one-fifth occur also in the Carboniferous beds below. These Carboniferous species are mainly those of wide range, as shown in the following catalogue:—

Streptorhynchus Umbraculum (fig. 550).	Chonetes Flemingii N. & P.
" Missouriensis Swallow.	Rhynchonella Osagensis, Swall.
Spirifer cameratus (fig. 591).	Athyris subtilita Hall.
" planoconvexus Shumard (=S. Urii?)	Mytilus rectus Shumard.
" pectiniferus? Sow.	Myalina subquadrata Shumard.
Productus semireticulatus (fig. 229) Martin.	" Kansasensis Shumard.
" Rogersi (fig. 592) N. & P.	Allorisma Minnehaha Swall.
" æquicostatus Shumard.	Naticopsis Pricei Shumard.

The species *Monotis Halli* Swallow, and two or three others, occur in both his Upper and Lower Permian. *M. Hawni* M. & H., *M. concava, Bakewellia antiqua, Solen* (?) *Permianus, Schizodus Rossicus, Murchisonia subangulata* ?, *Nautilus Permianus, Orthoceras Kickapooense, Cyrtoceras dorsatum,* are found only in the Upper.

III. General Observations.

The several points west of the Mississippi at which the Permian rocks have been found, prove at least their wide distribution over the Rocky Mountain slopes, although now to a great extent covered by strata of later date,—the Triassic, Jurassic, Cretaceous, and Tertiary. We observe the following facts connected with the period: (1.) The beds are apparently all marine strata, for the fossils are marine. (2.) The numerous alternations between impure limestones and clays and some sand deposits indicate oscillations through the period in the depth of water between moderate depths and very shallow waters. (3.) The absence of coal beds is proof of no fresh-water Carboniferous marshes in the regions where the rocks have thus far been examined. (4.) The non-occurrence of these marine strata over the region east of the Mississippi (with perhaps a single exception near the river in Illinois) seems to show that this eastern part of the continent was dry land. Early in the Carboniferous period, the Pennsylvania region was raised and became dry even of its old marshes, for only the *Lower* Coal measures occur there; and in the Permian period, as it appears, the dry region had extended so as to include all the country east of the Mississippi. (5.) The beds occur within the same region, or on the borders of the same region, in which the Coal formation during the Carboniferous period was represented by limestones; that is, in the great interior sea which had so long existed as the Palæozoic representative of the Gulf of Mexico,—a comparatively shallow, but extensive, inland sea stretching northward. The present western limit of the Gulf is nearly in a north-and-south line with the western boundary of the State of Kansas.

The existence of these Permian deposits is, then, owing to a con-

tinuation of the conditions that characterized the Carboniferous period. That era, limestone-making over these western regions, was prolonged into another when the limestones formed still, but with numerous interruptions by clay-depositions; and these alternations were perhaps due to an increasing frequency in the oscillations and shallowness of the waters.

The beds are continuous with the Carboniferous, without interruption or unconformability, and yet are true *Permian*, because they belong to the Permian period in geological time,—a fact indicated by the identity of genera, and the close analogy of the species of fossils with the Permian of Europe.

2. FOREIGN PERMIAN.

I. Rocks: kinds and distribution.

The Permian strata of England occur in view along the borders of the several coal regions, excepting that of South Wales. They occupy a small area in Ireland about the Lough of Belfast. They consist of *red sandstone and marls* overlaid by *magnesian limestone*. In Europe the Permian beds in like manner border directly upon the Coal measures, and the rocks are similar in general character to those of England.

The Permian beds, before their relations were correctly made out, were included, along with part of the Triassic, under the name "New Red Sandstone," and also the "Poikilitic group."

They occur in central Germany from southern Saxony along the Erz Mountains, over the small German States, west to Hesse Cassel and north to the Hartz Mountains and Hanover, adjoining. Within this area Mansfeld is one noted locality, situated in Prussian Saxony, not far from Eisleben; another is on the southwest borders of the Thuringian forest (Thüringerwald), in Saxe-Gotha, a line which is continued on to the northwest by Eisenach towards Münden in southern Germany.

In Russia the Permian formation, according to Murchison, covers a region twice the size of France, extending over the districts that lie along the west side of the Urals,—Vologda, Perm, and Orenburg,—and others more to the west, and thus including the country between the Volga and the Urals.

In Thuringia and Saxony the subdivisions of the rocks are (1) the red beds (or *rothe todte liegende, Red dead layers*,—a sandstone so called because the beds are red and contain no copper), overlaid by the copper slates (*Kupferschiefer*,—a clay-slate worked for its copper at Mansfeld). 2. The magnesian limestone, consisting of (*a*) *Lower Zechstein*, a gray, earthy limestone; (*b*) *Upper Zechstein*; (*c*) *Rauchwacke*, a shale partly calcareous and concretionary; (*d*) *Stinkstein*, an impure, fetid limestone. The limestone in England has four divisions:

(*a*) compact; (*b*) fossiliferous; (*c*) brecciated; and (*d*) crystalline and other limestones.

In Russia there are magnesian limestones interlaminated with sandstones, and marls of various colors, with some gypsum, and an occasional thin seam of coal.

The coincidence is worth noting that the Permian rocks of Russia or interior Europe lie between its great river the Volga and the summit of the Ural Mountains, just as in interior North America they occur between its great river the Mississippi and the Rocky Mountain summits. It may be that on both continents the region between the great river and the ocean had been raised above the sea during the preceding changes.

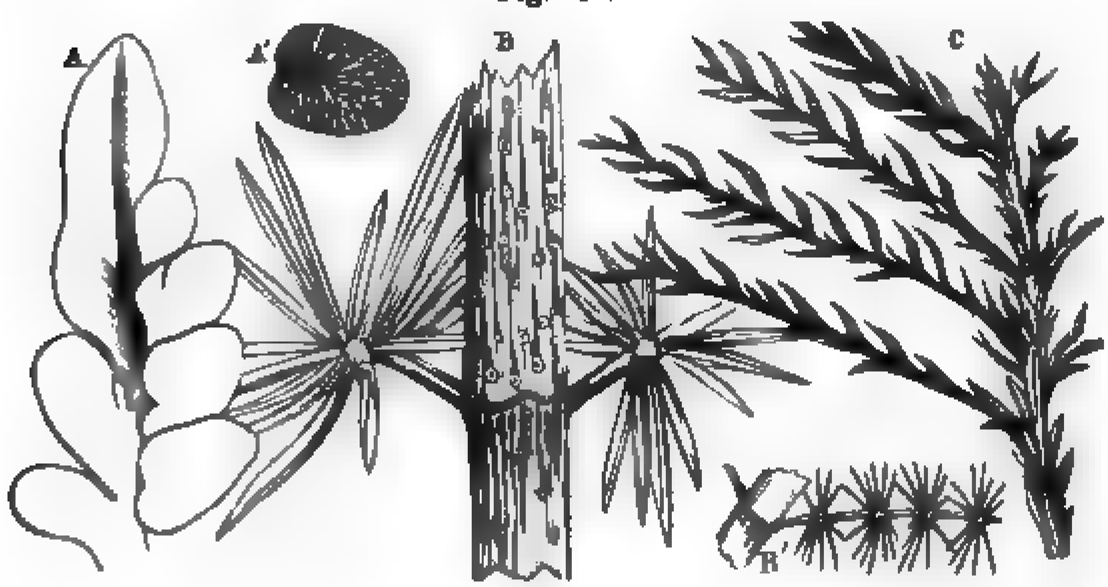
II. Life.

1. *Plants.*

The Permian plants are closely related to those of the Upper Coal measures. They are mostly of the same genera, and in part of the same species. There are Calamites and Equiseta, many ferns, including tree-ferns, and a number of Conifers: yet the prevalence of some new kinds gives a somewhat different aspect to the flora. Among the trees those of the genus *Walchia* (fig. 616 C) are most characteristic.

The Ferns are of the genera *Neuropteris*, *Sphenopteris*, *Pecopteris*, etc., and there are also species of *Asterophyllites* and *Annularia*, as well as *Calamites*,

Fig. 616.



Figs. 616 A, A′, Neuropteris Loschii; 616 B, B′, Annularia carinata; 616 C, Walchia piniformis.

Coal Measure genera. On the other hand, there are no *Sigillariæ*. The Conifers are more varied: they include *Araucarites* (*Dadoxylon*), *Pinites*, *Walchia*, etc.

The genus *Walchia*, characterized by lax and very short, spreading leaves, began near the close of the Carboniferous period, but is much more numerous in species during the Permian. Tree-ferns of the genus *Psaronius* are common, as in the Upper Coal measures.

Fig. 616 A, pinnule or branchlet of a large frond of *Neuropteris Loschii*, a species common also in the Coal measures; A', a portion showing the venation. Fig. 616 B, a small part of a specimen of *Annularia carinata* Sternberg; the stem is jointed, as in the Equiseta, and gives off branchlets at the articulations; these branchlets are also jointed, and have whorls of leaf-like appendages at the articulations; in 616 B, only the first joint and its whorl are shown, of natural size; in B' a branch is shown (of reduced size), consisting of its several joints and whorls, but the natural termination is wanting. Fig. 616 C, *Walchia piniformis* Sternberg. The figures are from the work of Geinitz and Gutbier on the Permian of Saxony.

2. *Animals.*

Corals of the *Cyathophyllum* family, Brachiopods of the genera *Productus*, *Spirifer*, and *Orthis*, Cephalopods of the genera *Conularia* and *Orthoceras*, and Ganoid fishes, with vertebrated or heterocercal tails, give a Palæozoic character to the Fauna. But there are many new features: among these the most prominent is the appearance of Lacertian Reptiles of the tribe of *Thecodonts*,—species having the *teeth set in sockets*, as the name (from the Greek) implies. This transition-character is apparent also in the number of old animal as well as vegetable types that here fade out,—for it is the period of the last of the species of *Productus*, *Orthis*, *Murchisonia*; the last of the extensive tribe of *Cyathophylloid* corals, which made coral reefs far greater than those of modern seas; nearly the last of the extreme vertebrate-tailed (heterocercal) *Ganoid* fishes. These groups had already dwindled much before the Permian period; for some prominent Carboniferous genera, as the *Goniatites*, do not reach into it. The old or Palæozoic world was dying out, while within it new types were coming forth, prophetic of the earth's brighter future.

Characteristic Species.

1. **Radiates.**—(*a.*) *Polyps.*—Cyathophylloid Corals; also corals of the genus *Stenopora* (*Chætetes*). (*b.*) *Echinoderms.*—Crinoids of the genus *Cyathocrinus*, a Palæozoic genus; Echinoids of the genus *Eocidaris*, near the Palæozoic *Archæocidaris*.

2. **Mollusks.**—(*a.*) *Bryozoans.*—*Fenestella retiformis*, found in the Permian of Russia, England, and Germany, besides a dozen other related species.

(*b.*) *Brachiopods.*—*Spirifer undulatus* Sowerby, from England, Lower Zechstein in Saxony,—some specimens two and a half inches broad; *Spirifer cristatus*, from the Zechstein, Germany; *Productus horridus* Sowerby, from England

and Germany, characteristic particularly of the Lower Zechstein, and occurring also in the Kupferschiefer; *Strophalosia excavata*, England, Germany (the species of the genera *Productus* and *Strophalosia* are exceedingly abundant in individuals); *Camarophoria Schlotheimi* von Buch, from Russia, Germany, and England (the genus is related to *Terebratula* and *Pentamerus*, and is peculiar to the Carboniferous and Permian); *Camarophoria superstes*, Russia.

(*c.*) *Conchifers.*—*Monotis speluncaria*, England, Russia, and Germany in the Lower Zechstein; *Mytilus* (*Modiola*) *Pallasi*, Russia and Germany; *Mytilus squamosus*, Russia, England; *Avicula Kazanensis*, Russia, Germany; *Bakewellia antiqua*, England, Russia, Germany; *Axinus dubius* Schlotheim, a very common species in England, Germany, and Russia. (It includes *Schizodus Schlotheimii* Geinitz, *Ax. obscurus* Sowerby, and other so-called species.) The genus *Axinus* is of the same family with *Trigonia*, a characteristic genus in the Reptilian age.

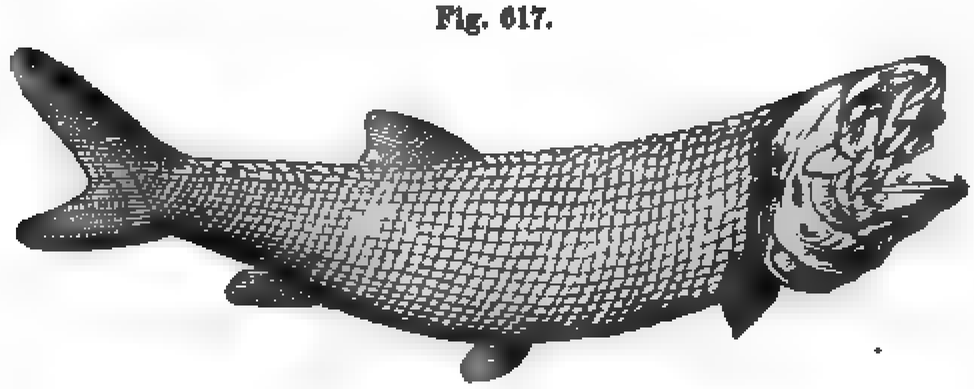
(*d.*) *Gasteropods* are rare in the Permian. There are a few species of *Murchisonia* and *Straparollus*, Palæozoic genera, besides some others.

(*e.*) *Cephalopods* existed, and among them two or three species of *Orthoceras*.

3. **Articulates.**—No *Trilobites* are known. *Ostracoids* are common. The first of the *Tetradecapods* (p. 153) is found in this formation.. The only species known is an Amphipod, *Prosoponiscus problematicus*, from the Permian of Durham, England, first described by Schlotheim, but recently explained by Bates. *Decapods* of the order of *Macrourans* appear to have commenced in the Coal formation. But the first of the *Brachyurans* is announced from the Permian by von Schauroth, who names it *Hemitrochiscus paradoxus*; Geinitz regards it as related to the Pinnotheres family, one species of which is the little crab found in the oyster: length about one-eighth of an inch.

4. **Vertebrates.**—(*a.*) *Fishes.*—Fig. 617, *Palæoniscus Freislebeni* Agassiz, one-third the natural size. Common in the Kupferschiefer, and also found in the Coal measures in England at Ardwick. Over forty species of fishes have been

Fig. 617.



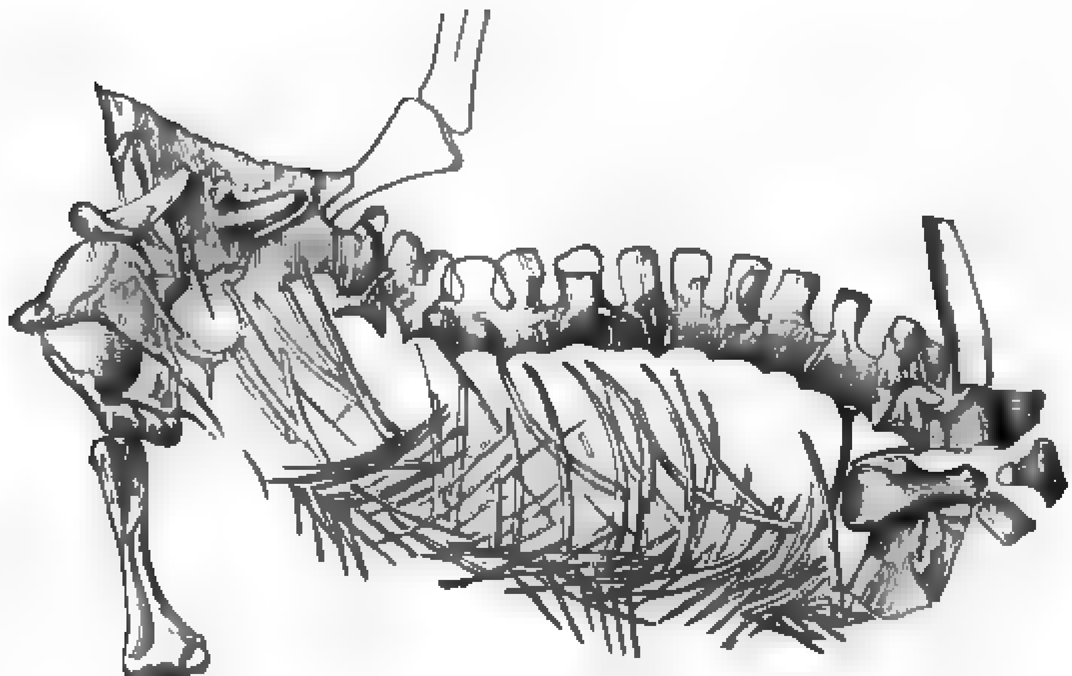
Palæoniscus Freislebeni (× ⅓).

described. The more characteristic genera are *Palæoniscus*, *Platysomus*, *Acrolepis*, *Pygopterus*, and *Cœlacanthus*, but they are also all Carboniferous.

(*b.*) *Reptiles.*—Nine or ten species have been described belonging to the tribes of Labyrinthodonts and Lacertians. Fig. 617 A, *Proterosaurus Speneri*, regarded

as a Thecodont Lacertian. It was three and a half feet long, and is from the copper-slate (Kupferschiefer) of Germany and Saxony. *Palæosaur* and *Thecodontosaur* are the names of other Permian genera of Thecodonts.

Fig. 617 A.



Proterosaurus Speneri.

The Permian Thecodont Reptiles are related in many points to the lizards and monitors (see p. 346), yet have biconcave vertebræ like the inferior swimming reptiles, united to the socket-teeth of the Crocodiles. The teeth are flattened and crenulate at the margins. The fingers in the *Proterosaurus* call to mind those of the Pterodactyl, as Gutbier suggests. The name Proterosaurus is from προτερος, *first*, and σαυρος, *lizard*, or *saurian*, and Palæosaurus from παλαιος, *ancient*, and *saurus*.

The characteristics which seem to be marks of high grade in these Thecodonts appear to be so implanted in a structure otherwise low, that they must be regarded as foreshadowings of the higher types rather than as marks of elevation.

The Palæozoic character of the life of the Permian, as already shown, is strongly marked. Geinitz observes, further, that the *Terebratula elongata* of the Zechstein approaches a Devonian form; *Camarophoria Schlotheimi* (Zechstein) is near the Carboniferous *C. Crumena*; *Spirifer Clannyanus* (Zechstein), the Carboniferous *S. Urii*, *S. cristatus*, the Carboniferous *S. octoplicatus*. The genus *Axinus* (Schizodus) ends with the Permian, as well as *Orthis*, *Camarophoria*, *Productus*, and *Strophalosia*.

GENERAL OBSERVATIONS ON THE PALÆOZOIC AGES.

I. Rocks.

1. *Maximum thickness.*—The maximum thickness of the rocks of North America of the Silurian age is 22,000 feet; of the Devonian age, about 14,400 feet; and of the Carboniferous age, nearly 15,000 feet.

2. *Origin.*—The fragmental rocks of the series—that is, the shales, sandstones, and conglomerates—were made from pre-existing rock-material through the agency of water, and mainly the waters of the ocean. They were formed over the continents during their more or less general submergence, and mostly in shallow waters or along the borders of the land left uncovered by the sea.

The limestones were formed, without probably an exception, from the calcareous relics of the living species. They were accumulated generally in pure ocean-waters, like the coral limestones of the present period; and hence, while protected from the incursion of detritus, perhaps, by barriers of some kind, they must still have had open communication with the sea. But, as in the case of the coral reefs, the waters, although sometimes deep, may generally have been shallow, so that the waves could perform their part in grinding up and compacting the rising reef. When the shells are unbroken, there is sufficient evidence that the waters were too deep for the heavy waves to reach them; but this does not necessarily imply more than a depth of a few fathoms.

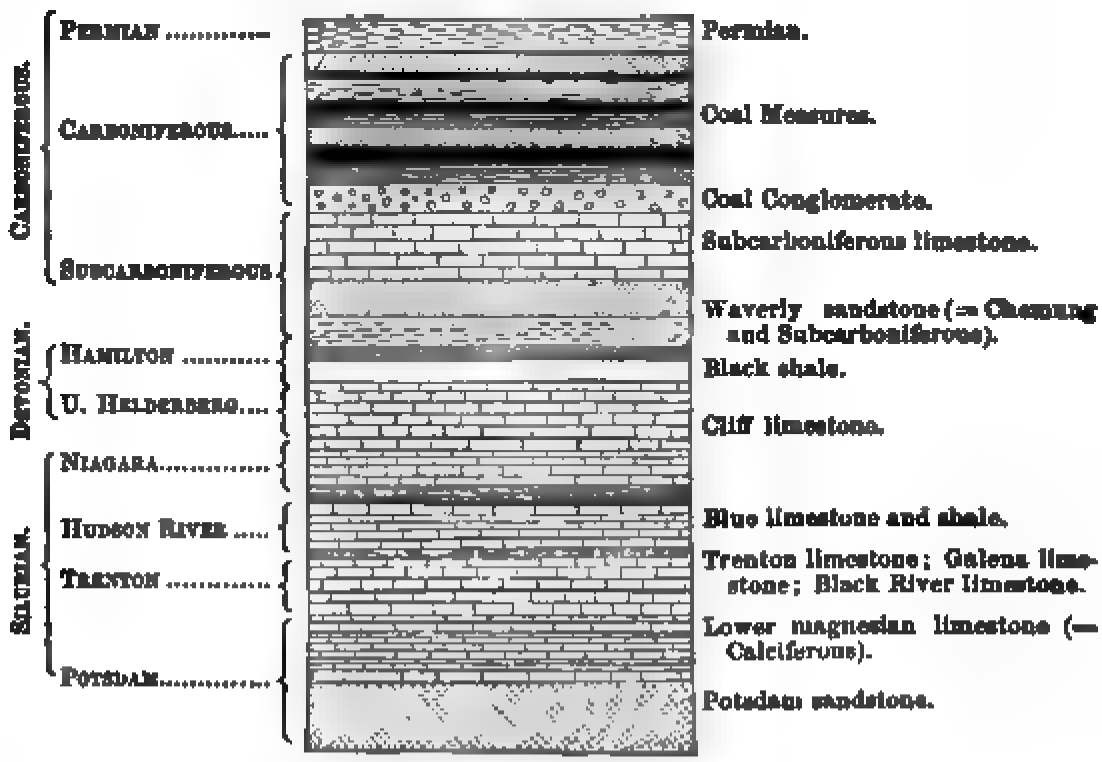
The hornstone, which is common in the limestones of the Palæozoic in some parts of the country, is proved by the observations mentioned on p. 270 to be mainly of organic origin. It is probable that in all cases in which the fossils of a limestone are siliceous (instead of calcareous) it is owing to the same cause that has originated the chert,—namely, the presence, in great profusion, of the siliceous remains of protophytes along perhaps with sponges.

3. *Diversities of the different Regions of the continent with regard to the kinds of rocks.*—The three regions into which the portion of the continent which has been especially considered is divided are (1) the Interior Continental region, (2) the Appalachian region, and (3) the Eastern border region. The rocks of the Appalachian region are mainly fragmental, the limestones forming only a fourth of the whole thickness. The strata of the Interior Continental basin are mostly limestones, these constituting full two-thirds of the series. Although New York is situated mostly within the Interior basin, it still adjoins the Appalachian region, and partly lies within its border. Some idea

of the contrast between the two regions may be gathered from a comparison of the section of the New York rocks, on p. 131, with the general section of the formations in the Mississippi valley here presented.

In the Lower Silurian of this section the Calciferous beds are mainly of limestone, as well as the Trenton and the greater part of

Fig. 618.



Section of the Palæozoic rocks in the Mississippi basin.

the Hudson. The Upper Silurian contains little but limestone; the Lower Devonian and the Subcarboniferous are also limestone. Moreover, many limestone beds intervene in the Coal measures; and west of the Mississippi, over a considerable portion of the Rocky Mountain slope the Carboniferous beds are mainly limestones.

The rocks of the northern border of the Interior Continental basin towards the Azoic contain a much smaller proportion of limestone than those of the central portion.

The contrast between the Appalachian region and the Interior will become more apparent from a few general sections. The *first* here given is from the State of Pennsylvania, which lies within the Appalachian region; it is from the Geological Report of H. D. Rogers; the *second* is a section of the Michigan rocks, by A. Winchell, lying on the northern side of the Interior basin; the *third*, of Iowa, which is also on the northern side, by Hall; the *fourth* and

fifth, of Illinois and Missouri, which are near its centre,—the former by A. H. WORTHEN, the latter by G. C. SWALLOW, but with changes from more recent information; the *sixth*, of Tennessee, the eastern part of which is in the Appalachian region, and the middle and western in the Interior, by J. M. SAFFORD. In each case the sections begin below.

1. *Pennsylvania Section.*

Lower Silurian.

POTSDAM, *Potsdam Epoch.*—"Primal Series" of Rogers,—Sandstones and Slates, 3000–4000 feet.

Calciferous Epoch.—"Auroral" Calcareous Sandstone, 250 feet.

TRENTON, *Chazy Epoch.*—"Auroral" Magnesian Limestone, with some cherty beds, 5400 feet.

Trenton Epoch.—"Matinal" Limestone with blue shale, 550 feet.

HUDSON, *Utica Epoch.*—"Matinal" bituminous slate, 400 feet.

Hudson Epoch.—"Matinal" blue shale and slate, with some thin gray calcareous sandstones, 1200 feet.

Upper Silurian.

NIAGARA, *Oneida Epoch.*—"Levant Gray" Sandstone and Conglomerate, 700 feet.

Medina Epoch.—"Levant Red" Sandstone and Shale, 1050 feet; and "Levant White" Sandstone, with olive and green shales, 760 feet: total, 1810 feet.

Clinton Epoch.—"Surgent Series," Shales of various colors, both argillaceous and calcareous, with some limestones, ferruginous sandstones, and iron-ore beds, 2600 feet.

Niagara Epoch.—Not well defined; possibly corresponds to part of the "Surgent" Series.

SALINA, *Saliferous Epoch.*—"Scalent" Variegated marls and shales, some layers of argillaceous limestone, 1650 feet.

LOWER HELDERBERG.—"Scalent" Limestone, thin-bedded, with much chert, 350 feet; "Pre-meridian" encrinal and coralline limestone, 250 feet: total, 600 feet.

Devonian.

ORISKANY, *Oriskany Epoch.*—"Meridian" calcareous shales, and calcareous and argillaceous sandstone, 520 feet.

CORNIFEROUS, *Cauda-Galli Epoch.*—"Post-meridian" silico-calcareous shales, 200–300 feet.

Upper Helderberg Epoch.—"Post-meridian" massive blue limestone, 80 feet.

HAMILTON, *Marcellus Epoch.*—"Cadent" Lower black and ash-colored slate, with some argillaceous limestone, 800 feet.

Hamilton Epoch.—"Cadent" argillaceous and calcareous shales and sandstone, 1100 feet.

Genesee Epoch.—"Cadent" Upper black calcareous slate, 700 feet.

CHEMUNG, *Portage Epoch.*—"Vergent" dark-gray, flaggy sandstones, with some blue shale, 1700 feet.

Chemung Epoch.—"Vergent" gray, red, and olive shales, with gray and red sandstones, 3200 feet.

CATSKILL.—"Ponent" red sandstone and shale, with some conglomerate, 6000 feet.

Carboniferous.

SUBCARBONIFEROUS, *Lower.*—"Vespertine" coarse, gray sandstones and siliceous conglomerate at the eastward, becoming fine sandstones and shales at the westward, 2660 feet.

Upper.—"Umbral" fine red sandstones and shales, with some limestone, 3000 feet.

CARBONIFEROUS, *Millstone-Grit Epoch.*—"Seral" siliceous conglomerate, coarse sandstone and shale, with some fine argillaceous shales, including coal-beds, 1100 feet.

Coal Measures.—Sandstone and shale, with some limestone, 2000–3000 feet.

2. *Michigan (Lower Peninsula) Section.*

Lower Silurian.

POTSDAM, *Potsdam Epoch.*—"Lake-Superior Sandstone," mottled, reddish, or dark and shaly, at Sault St. Mary, 18 feet; more to the westward, 250 feet.

Calciferous Epoch.—Rocks of this epoch said to exist,—character and thickness not known.

TRENTON, *Chazy Epoch.*—Gray siliceous limestone, 2 feet.

Trenton Epoch.—Blue and argillaceous limestone, with green calcareous shale, 30 feet.

HUDSON.—Argillaceous limestone underlaid by bluish-gray subcrystalline limestone, 18 feet or more.

Upper Silurian.

NIAGARA, *Clinton Epoch.*—Argillaceous, bituminous, and calcareous limestones, 51 feet.

Niagara Epoch.—White and gray limestones, massive and crystalline, some layers arenaceous, others geodiferous, 97 feet.

SALINA, *Saliferous Epoch.*—Brown and gray argillaceous limestones, calcareous clay, and variegated gypseous marls, 37 feet.

Devonian.

ORISKANY, *Oriskany Epoch.*—Cherty, sometimes agatiferous conglomerate, 3 feet.

CORNIFEROUS, *Upper Helderberg Epoch.*—Brecciated limestone, 250 feet; overlaid by oolitic, arenaceous, and bituminous limestones, 104 feet: total, 354 feet.

HAMILTON, *Marcellus (?) Epoch.*—Black, bituminous limestone, 15 feet.

Hamilton Epoch.—Argillaceous limestones, 17 feet; crystalline limestone with included lenticular clayey masses, 23 feet: total, 40 feet. Contains a bed of coal on Little Traverse Bay.

Genesee (?) Epoch.—Black, bituminous shale, 20 feet,

CHEMUNG, *Portage Epoch.*—"Huron" shales with intercalated flagstones and limestones, 190 feet.

Carboniferous.

SUBCARBONIFEROUS, *Lower.*—"Huron" and "Marshall" (= Chemung?) gritstones, and reddish, yellowish, and greenish sandstones and conglomerates, 173 feet; "Napoleon sandstone," generally micaceous, with clay beneath, 123 feet; "Michigan Salt-group," carbonaceous and argillaceous shales, magnesian and arenaceous limestones, and thick beds of gypsum, 184 feet: total, 480 feet.

Upper.—Limestones, arenaceous below, 66 feet.

CARBONIFEROUS, *Millstone-Grit Epoch.*—"Parma" thick-bedded sandstone, in some places conglomeritic, 105 feet.

Coal Measures.—Bituminous shales, and fire-clays, with occasional thin sandstones and limestones, 123 feet; "Woodville" sandstone, 79 feet: total, 202 feet.

3. *Iowa Section.*

Lower Silurian.

POTSDAM, *Potsdam Epoch.*—Very pure sandstone, with some thin, calcareous, shaly layers, 500 feet.

Calciferous Epoch.—"Magnesian" limestone, almost chemically pure, sometimes brecciated and concretionary, 250 feet or more.

TRENTON, *Chazy Epoch.*—"St. Peter's Sandstone," a granular, rarely compact sandrock, 80 feet.

Trenton Epoch.—"Buff," "Blue" and "Galena" magnesian limestones, with some shaly portions in the lower layers, 350 feet.

HUDSON, *Hudson Epoch.*—Siliceous and argillaceous shales, mostly bituminous, 80–100 feet.

Upper Silurian.

NIAGARA, *Clinton and Niagara Epochs.*—Light yellowish-gray compact magnesian limestone, with much chert, 150–300 feet.

SALINA, *Leclaire Epoch.*—Gray semi-crystalline porous limestone, 600–700 feet.

Saliferous Epoch.—Thin-bedded, drab-colored limestones, with shaly partings, 100–150 feet.

Devonian.

CORNIFEROUS, *Upper Helderberg Epoch (?).*—Gray compact limestone, with some concretionary and shaly layers, 50 feet or more.

HAMILTON, *Hamilton Epoch (?).*—Magnesian limestones, 100 feet.

CHEMUNG, *Chemung Epoch.*—[Subcarboniferous in part?] Siliceous shales, sometimes calcareous, 100 feet or more.

Carboniferous.

SUBCARBONIFEROUS.—Consisting of—1st, "Burlington" subcrystalline encrinital limestone, 100 feet or more; 2d, "Cherty" limestone, 100 feet; 3d, "Keokuk" bluish-gray limestone, with thin beds of shale, 40 feet, and calcareous shale filled with "geodes," 40 feet; 4th, "Warsaw" magnesian limestone, succeeded by shaly limestone and coarse, calcareous sandstone, 40 feet; 5th, "St. Louis" limestone, commonly brecciated and concretionary, in some parts compact, 20 feet or more: total, 340–400 feet.

CARBONIFEROUS.—Shale, sandstone, clay, and limestone, less than 500 feet.

4. *Illinois Section.*

Lower Silurian.

POTSDAM, *Calciferous Epoch.*—Buff magnesian limestone, with beds of earthy hydraulic limestone, 100 feet or more.

TRENTON, *Chazy Epoch.*—"St. Peter's Sandstone," brown and white friable sandstones, in some places concretionary, 150 feet.

Trenton Epoch.—"Trenton" and "Galena" brown magnesian limestones, thin-bedded blue limestones, and massive gray granular limestones, 300 feet.

HUDSON, *Hudson Epoch.*—Shales, shaly sandstones, and dark-blue limestone, 100 feet.

Upper Silurian.

NIAGARA.—Buff and gray magnesian limestone, some cherty beds, 300 feet.

Devonian.

ORISKANY.—Quartzose sandstone, becoming locally calcareous, 50 feet.

HAMILTON, *Hamilton Epoch.*—Coralline limestone and shale, dark-colored fetid limestone, 120 feet.

Genesee Epoch.—"Black Slate," bituminous shales and slates, 40 feet.

Carboniferous.

SUBCARBONIFEROUS.—Consisting of—1st, "Kinderhook" arenaceous and argillaceous shales with local beds of limestone, 100 feet; 2d, "Burlington" light-gray limestones with chert, and brown, arenaceous limestones, 200 feet; 3d, "Keokuk" calcareo-argillaceous shales with geodes, gray limestones, and chert, with seams of stratified marly clay, 100 feet; 4th, "Warsaw" and "St. Louis" bluish-gray limestone, concretionary and brecciated beds, impure limestones and clay shales, magnesian limestone, 200 feet; 5th, massive "Ferruginous" sandstone of even texture, 100 feet; 6th, "Chester" limestones, separated by heavy beds of clay shale, which pass locally into sandstone, 250 feet: total, 950 feet.

CARBONIFEROUS, *Millstone-Grit Epoch.*—Sandstone and conglomerate, 300 feet.

Coal Measures.—Sandstones and shales, with thin bands of limestone and five or more coal-seams, 900 feet.

5. *Missouri Section.*

Lower Silurian.

POTSDAM, *Calciferous Epoch.*—Alternations of crystalline and compact "Magnesian Limestones," and white or gray pulverulent or firm "Saccharoidal Sandstones," 1300–1500 feet.

TRENTON, *Trenton Epoch.*—Bluish-gray and drab compact limestone, with conchoidal fracture; buff and gray crystalline limestone, much decomposed on exposure; some blue shale; 435 feet; overlaid by "Receptaculite" argillaceous subcrystalline limestone, 130 feet: total, 565 feet.

HUDSON, *Hudson Epoch.*—Two beds of blue and gray argillaceous magnesian limestone, 60 feet, separated by blue and purple shales, 60 feet: total, 120 feet.

Upper Silurian.

NIAGARA, *Niagara Epoch.*—Compact magnesian and argillaceous limestone, 150 feet.

LOWER HELDERBERG.—Light-gray magnesian limestone, 100 feet.

Devonian.

ORISKANY.—Light-gray, nearly pure limestone,—thickness not given.

CORNIFEROUS, *Upper Helderberg Epoch.*—Gray, compact, earthy-limestone with chert and some sandstone; in some parts a hard white oolite, 75 feet.

HAMILTON, *Hamilton Epoch.*—Blue argillaceous shale, with thin layers of concretionary limestone, 50 feet.

Genesee Epoch.—Black slate, 6 feet.

Next follow beds which have been referred by some to the Chemung group, by others to the Subcarboniferous,—viz.: 1st, Light-drab, fine, compact "Lithographic" siliceous limestone, 70 feet; 2d, buff, fine-grained, pulverulent, argillo-calcareous sandstone, with some magnesian limestone, underlaid by blue or brown argillaceous shale, 100 feet; 3d, fine, compact limestone, overlaid by brown silico-magnesian limestone, 70–120 feet: total, 250–300 feet.

Carboniferous.

SUBCARBONIFEROUS.—1st, "Encrinital," brown, buff, gray and white, coarse crystalline heavy-bedded limestone, everywhere containing chert, 500 feet; 2d, "Archimedes" gray and drab crystalline and compact limestone, with some silico-argillaceous limestones and blue shales, 200 feet; 3d, "St. Louis" hard, crystalline, gray, cherty limestone, with thin beds of argillaceous shale, 250 feet; 4th, "Ferruginous" brown and red, coarse, friable sandstone, in some parts white and "saccharoidal," 200 feet: total, 1150 feet.

CARBONIFEROUS, *Coal Measures.*—Blue and gray compact limestones, with black, blue, and purple bituminous and calcareous shales, and a few thin beds of coarse sandstone, 250 feet or more.

6. *Tennessee Section.*

Lower Silurian.

POTSDAM, *Potsdam Epoch.*—"Chilhowee" sandstones and sandy shales, at least 1000 feet in *east Tennessee.*

Calciferous Epoch.—Fine sandstones and shales, with magnesian limestone: sandstone member (lowest), 600–1000 feet in *east Tennessee;* shales, 1500–2000 feet; limestone, 3500–3800 feet.

TRENTON, *Trenton Epoch.*—"Stones River" blue and dove-colored limestones, with more or less chert, 500–600 feet in *east Tennessee;* lower part of "Nashville Group."

HUDSON, *Utica* and *Hudson Epochs.*—Upper part of "Nashville Group," calcareous shales and argillaceous limestones, including beds of fine marble, 1000–2000 feet in *east Tennessee.*

Upper Silurian.

NIAGARA, *Medina Epoch.*—"Clinch Mountain" white and gray sandstone, and "White Oak Mountain" brown sandstones and shales, 800–1000 feet.

Clinton Epoch.—"Dyestone Group," variegated calcareous shales with some sandstone, 200–300 feet in *east Tennessee.*

Niagara Epoch.—"Sneedville" gray limestone, 200 feet thick.

LOWER HELDERBERG.—Gray crinoidal limestone, 75–100 feet in *middle Tennessee;* absent elsewhere (?).

Devonian.

HAMILTON (?), *Genesee Epoch.*—"Black Slate," a brownish-black slate, often pyritiferous and bituminous, 100 feet or more in *east Tennessee.*

Carboniferous.

SUBCARBONIFEROUS, *Lower.*—"Siliceous Group," shales and sandstone, 400 feet at Cumberland Gap (perhaps Upper Devonian); blue and gray limestone, mostly cherty, with some shale, 300–550 feet.

Upper.—"Mountain" limestone, blue, thick-bedded, and in great part oolitic, 500–750 feet in *middle Tennessee.*

COAL MEASURES.—Sandy conglomerates, sandstones with six or more coal-beds, and shales, 2500 feet or more in *middle Tennessee.*

In the *Eastern border region,* about the Gulf of St. Lawrence (which was probably an interior basin like the Interior Continental) there were limestones forming almost continuously from the Calciferous epoch in the Lower Silurian to the close of the Clinton epoch in the Upper Silurian, which is the last of the formations there observed. With regard to other parts of the Eastern border region our knowledge is yet imperfect, and in great measure because the crystallization which the rocks have undergone has obliterated most of their original features. This is the case over New England and the

border of the continent south of New York. Besides this, a strip of land some eighty miles wide, constituting the eastern margin of the continental plateau, is still under water (p. 12). The map, fig. 664, gives a general view of the breadth and depth of this plateau off the coast of New Jersey.

4. *Diversities in the different regions as to the thickness of the rocks.*—The maximum thickness mentioned on p. 377—50,000 feet—occurs in the Appalachian region. It is not found in any one place; for some of the formations are thickest along the middle of the region, others on the western side, and still others on the eastern; and, again, the beds of the Carboniferous age are most largely developed to the northeast in Nova Scotia. Owing to facts like these, the maximum amount exceeds considerably the actual thickness of the accumulations over the region. Still, it cannot be less than 36,000 feet, or 6½ to 7 miles. Each of the successive formations in the Appalachian region is remarkable for its great thickness from the Potsdam upward.

In the central portions of the Interior Continental basin the thickness varies from 3500 (and less on the north) to 6000 feet. It is, therefore, from *one-sixth* to *one-tenth* that in the Appalachian region.

Another region of unusual thickness lies on the north side of the Interior basin, near the Azoic. Along Lakes Superior and Huron the fragmental Huronian beds in the closing part of the Azoic age accumulated to a thickness of 10,000 feet; and in the latter part of the Potsdam period the Calciferous beds in some places about the former lake have a thickness of 3000 to 4000 feet. Again, in the region of the St. Lawrence, about Ottawa, the Potsdam beds have *twice* the thickness they exhibit in the State of New York, and the Trenton in Canada are *three* times as thick, or nearly 1000 feet,—an unusual thickness for a limestone formation.

In Missouri, during the Calciferous epoch, in the Potsdam period, the accumulations had the great thickness of 1300 feet,—an exception to the usual fact in the Interior Continental region.

Relative duration of the Palæozoic ages.—The thickness of the series of rocks pertaining to the several ages affords some data for estimating their *time-ratios*. The results are necessarily uncertain, since the increase of a rock is often directly connected with the subsidence there in progress, as has been sufficiently explained. Still, the conclusions are sufficiently reliable to be here presented.

Taking the maximum thickness along the Appalachians of the successive formations (the limestone and fragmental beds in each case from the same region), we find for the

	Fragmental rocks.	Limestones.
1. Potsdam period	6,800	200
2. Rest of Lower Silurian	1,600	6,000
3. Lower Silurian era	8,400	6,200
4. Upper Silurian era	6,760	600
5. Devonian Age	14,300	100
6. Carboniferous Age	14,600	125

Limestones increase with extreme slowness, as explained in the chapter on coral islands. From five to ten feet of fragmental deposits will accumulate while one of limestone is forming. This conclusion is sustained by the ratio in any given period between the fragmental rocks of the Appalachians and the limestones of the Interior basin.

Taking the ratio as 5 to 1, and making the substitution accordingly, the numbers are, respectively, (1) 7800; (2) 31,600; (3) 39,400; (4) 9760; (5) 14,800; (6) 15,225. These numbers have nearly the ratio $1:4:5:1\frac{1}{4}:2:2$. Hence, for the Silurian, Devonian, and Carboniferous ages, the relative duration will be $6\frac{1}{4}:2:2$, or not far from $3:1:1$. If the ratio 8 to 1 be taken, these numbers become $4:1:1$.

According to these calculations, the American Lower Silurian era was, by the first estimate, *four* times as long as the Upper; by the second, *five* times; and the duration of the Silurian age was *three* or *four* times that of either the Devonian or the Carboniferous. The earth thus dragged slowly on through its earliest periods.

II. American Geography.

1. *General course of progress.*—Through the Palæozoic ages, the dry land of the closing Azoic age (map on p. 136) gradually extended southeastward, southward, and southwestward. At the end of the Silurian, the limit of the dry land appears to have had its position near the central east-and-west line of the State of New York; and at the close of the Devonian it lay not far from the southern border of the State. Westward, beyond Michigan, in Illinois, Iowa, and Minnesota, there was a like expansion to the south and west of the Wisconsin Azoic. Michigan long continued to be a part of the oscillating Interior basin, the Palæozoic formations being continued there even to the close of the Coal period.

Along the St. Lawrence the Ottawa basin was nearly obliterated at the close of the Lower Silurian (p. 228). In the latter half of the Upper Silurian the river opened into a St. Lawrence gulf over the site of Montreal, and in its waters a Lower Helderberg limestone

was formed. In the Devonian age the head of the gulf was still farther to the northeast,—probably in the vicinity of Quebec,—and opened southward over New England; for coral reefs were growing in the region of Lake Memphremagog during the earlier Devonian (p. 270).

South of the eastern half of the St. Lawrence there appears to have been a progress of the dry land southward, similar to that over New York and the West; for the Silurian and Devonian beds are successively passed over in going towards New England. There is reason for believing, as different geologists have urged, that the granites and schists of the White Mountains were made of strata of the Devonian age. Still farther south, beyond Worcester, in Massachusetts, and over Rhode Island, lay the Carboniferous marsh or coal-making area of the New England basin; while to the northeast, over part of Nova Scotia and New Brunswick, there were the far larger marshes of the Acadian basin: the two belong geographically to the same great region—then low—between the St. Lawrence and the ocean, and probably had direct connection.

After the Devonian, and the Subcarboniferous period in the next age, the dry land expanded to nearly its present extent, and it became covered with forests, jungles, and marshes of Carboniferous vegetation. This condition oscillated with that of marine submergence many times in the progress of the Coal period. But the dry land appears to have reached a degree of permanence in the Appalachian region after the Pittsburg Coal series, and, to a still wider extent, throughout the whole interior east of the Mississippi, after the Upper Coal beds (p. 368), so that when the Carboniferous period closed, the continent in this its eastern half was almost complete. Over the whole surface, including New England, Canada, and the British possessions eastward, no rocks occur between the Palæozoic and Cretaceous, excepting small strips of Mesozoic east of the Alleghanies, and also in the Connecticut valley and Nova Scotia.

The interior sea, which in Silurian and Devonian periods had spread from the Gulf of Mexico over the whole Interior Continental basin and stretched northward on the west side of the Azoic nucleus to the Arctic, after many variations eastward and westward in its extent through the whole Palæozoic, was at last mostly limited to the region west of the Mississippi, and the southern portion of the Mississippi valley; for here are located all the marine sedimentary deposits of the interior formed in later time.

2. *Mountains.*—The mountains of the Palæozoic continent were mainly those of the Azoic,—the Adirondack, of northern New York, other heights in British America, the Black Hills, and iso-

lated ridges in the seas of the Rocky Mountain region, etc. The Carboniferous marshes covered a large part of the site of the Alleghanies, and a sea in which Carboniferous limestones were forming, a considerable portion—perhaps all but the Azoic heights—of the area of the Rocky Mountains.

But after the close of the Lower Silurian the Green Mountain region appears to have been above the sea (pp. 228, 243), and divided the New England or Eastern border region from the Interior. Consequently, the subsequent progress of the dry land over New England was from the Green Mountain region eastward, as well as from the St. Lawrence southward. In other words, the Devonian beds which stretch from Gaspé to Vermont, thence bend southward on the east of those mountains, as has been suggested by the geologists of Canada.

3. *Rivers.*—The rivers of the early Palæozoic were only small streams, such as might have gathered on the limited Azoic lands. In the later Devonian and the Carboniferous, they included the Hudson and St. Lawrence (p. 300). But even to the last, the region of the great streams of the Rocky Mountains was still a part of the interior sea; the Mississippi had but a part of its length, and this only temporarily, as the country was often submerged. The valley of the Ohio River was in part the region of the interior Carboniferous marshes: as the mountains in which it rises were not yet raised, the river cannot have existed. Moreover, the Cincinnati uplift (p. 228), which stretched southwestward into Kentucky and Tennessee, and may date from the beginning of the Upper Silurian, probably divided the great interior marshes about the upper Ohio region from those of the lower.

III. Oscillations of level.—Dislocations of the strata.

1. *General subsidence.*—The earliest Silurian beds—the Potsdam—bear abundant proof, in ripple-marks, sun-cracks, and wind-drifts, of their formation near the water-level. Many of the succeeding strata of the Silurian and Devonian periods contain the same evidence, and lead to the same conclusion for each; and later, in the Carboniferous formation, many layers show in a similar manner that they were spread out by the waves, or within their reach. Consequently, when these last layers of the Palæozoic in the Appalachian region were at the ocean's level, the Potsdam beds—though once also at the surface—were about *seven* miles below; for this is the thickness of the strata that intervene: seven miles of subsidence had, therefore, taken place in that region during the progress of the Palæozoic ages.

From analogous facts it is learned that the subsidence in the Interior Continental basin was about one mile, instead of seven. In the lower peninsula of Michigan it was at least 2500 feet; in Illinois, 3000 to 4000 feet; in Missouri, 5000 to 6000 feet.

On the northern border of the Interior basin, near the Azoic, the thickness of the Lower Silurian indicates a great subsidence in that era which was not afterwards continued. Thus, in the vicinity of the great lakes, the 10,000 feet of the Huronian in the last part of the Azoic age, and the 4000 of the Potsdam period, teach that near the beginning of Palæozoic time this was a region of unusual subsidence; and the igneous rocks that intersect and interlaminate the sedimentary strata evidently came up through the fractures that accompanied, or were occasioned by, the subsidence.

In Western Canada, between the stable Azoic of Canada and New York, the 1000 feet of Trenton limestone, and 700 feet of Calciferous and Potsdam beds, prove that there was a great subsiding also in that region, while little occurred south of the New York Azoic. After the Lower Silurian, this subsidence in the vicinity of the Azoic for the most part ceased.

In Missouri, also, where again there is a patch of Azoic, the thickness of the formations of the Potsdam period was 1500 feet or more.

All the numbers here given, both for the Appalachian region and the interior, are probably below the actual fact; for the strata may in many cases—especially along the Appalachian region—have lost much of their original thickness by denudation, either before or after they were consolidated. This loss may have been one-fourth the whole; but, whatever its extent, it probably has not altered the proportion of subsidence between the Appalachian region and the interior.

2. *Oscillations.*—The succession of sandstones, shales, and limestones in the Palæozoic series have been explained to be indications of as many changes in the water-level of the continent. The prevalence of limestones over the Interior basin has pointed out the region as an extensive reef-growing sea, opening south into the Atlantic, and perhaps also the Pacific, for the larger part of Palæozoic time. But there were slow oscillations in progress that changed the limits of the formations to the eastward or westward, as the periods succeeded one another.

The Potsdam sandstone covers both the Appalachian region and the Interior basin.

The Calciferous beds also stretched over both, but were partly limestone in the east, and mostly so in the west.

Trenton spread over both, with perhaps the exception of the Green tain portion; and, throughout, it was almost solely limestone.

e *Hudson* formations cover both, with the same exception as in the case of last; but they are shales in the East, and limestones mainly in the West.

he preceding are the universal formations. Passing now to the Upper urian:—

In the *Niagara* period, the Oneida conglomerate occurs in central New York nd along the Appalachians; the Medina beds have nearly the same position, ut also spread over Canada, west of New York, and are sandstones and marls; he Clinton beds have approximately the same eastern distribution, but spread farther to the west along the northern portion of the Interior basin, reaching to Wisconsin,—and, while mostly arenaceous in the East, they are in general calcareous in the West; the Niagara limestone has again the same position over central New York and the Appalachians, but extends over nearly the whole *Interior basin*, showing an expansion or change in the interior sea; and its rocks, excepting those of the Appalachians, are mainly limestones.

In the *Salina* period, there is the same extension of the formation from the Appalachians north over central New York, but to the west it spreads only along the north, where it reaches to Iowa; the rocks on the east are marls and sandstones, and those of the West mostly limestone.

In the *Lower Helderberg* period, the rocks stretch from central New York southwestward along the Appalachians, and do not spread much to the west of New York and Canada. The rock is a *limestone*,—the first of any extent in the Appalachians of Pennsylvania since the Trenton.

This extension of the Appalachian strata northward over central New York, and their maximum thickness there for those latitudes, have been accounted for on the supposition that the Green Mountain region became a part of the comparatively permanent dry land after the close of the Lower Silurian (pp. 228, 243), and, consequently, the oscillating area was transferred a little farther to the westward. It, however, did not reach north to the Azoic of New York, which was still a portion of the *stable* part of the continent.

In the Devonian age:—

The *Oriskany* formation was mainly confined to central New York and the Appalachians, but some thin beds occur in the Mississippi basin: the rocks are mostly sandstones.

The *Upper Helderberg* was the coral-reef period, and limestones were spread over the larger part of the *Interior basin*, and also over the Appalachians.

The *Hamilton* beds were extensive in central New York and along the Appalachians, but very thin to the westward over the interior: the "black slate" of the Genesee epoch is its thickest portion, and this is remarkable for its wide distribution over the Interior basin, and its persistent uniformity of character,—which proves that it must have been formed in waters of very uniform depth, either very shallow or somewhat deep,—probably the former.

The *Chemung* and *Portage* beds have great thickness in southern New York and the Appalachians, and are very thin to the west, and in many parts wanting: they are sandstones.

In the Carboniferous age:—

The *Subcarboniferous* formations are thousands of feet thick in the Appa-

lachians of Pennsylvania, and consist of sandstones, shales, and conglomerates with little limestone; in those of Virginia, the limestones are of great thickness: the formations cover the *Interior basin*, and are almost wholly of limestone, the lower part only being arenaceous or siliceous.

The *Carboniferous* Millstone grit is a conglomerate of great extent in the Appalachians, mostly a sandstone in Ohio, and is nearly wanting in the Mississippi basin. The Coal measure beds are shales and sandstones with little limestone in Pennsylvania and Ohio; shales and sandstones with considerable limestone in the Mississippi basin east of Kansas; and mainly limestone west of Kansas.

This brief sketch of the limits of the formations gives an idea of the great oscillations in the sea-level during the progress of the Palæozoic: it is not necessary to dwell upon its details, as the conclusions may be readily drawn by the reader after the explanations, under the head of *General Observations*, in the preceding pages. The Eastern border region has here been left out of view.

Until the close of the Subcarboniferous period, the oscillations had that wide continental range which was eminently characteristic of the American Palæozoic. In the period following, the Carboniferous, the continent for prolonged periods stood raised just above the ocean, at a nearly uniform level,—so low that its interior was covered with immense fresh-water marshes, and for so long eras that the vegetable accumulations attained the thickness sufficient for coal beds (p. 360); but these emergences had their alternation with submergences. The system of oscillations, though slower in movement, was still continued; yet the movements were less general; and it is therefore difficult to make out a parallelism in the beds of coal and intervening rock-strata through the East and West.

3. *Uplifts and dislocations.*—The only mountain-region along the course of existing chains which can now be pointed to as having emerged during the Palæozoic ages, is that of the Green Mountains. This region probably became part of the stable dry land in the interval between the Potsdam period of the Lower Silurian and the commencement of the Upper Silurian era.

The crystalline limestones of western New England have been referred to the Calciferous epoch. They extend from Connecticut through Massachusetts (in which State the Stockbridge quarries are most noted), and nearly to the northern limit of Vermont; and in Vermont, where they have been called "Eolian" limestones, they have, according to Hitchcock, a thickness of 2000 feet. If actually Calciferous, the emergence of the Green Mountain region may have taken place before the Trenton period, since no Trenton rocks in that case were formed over it. The fossils have in general been obliterated by the crystallization of the rock. But the Ver-

nt rock at Sudbury and elsewhere has afforded a few fossils, and ·se favor its belonging to the Trenton period, as long since held Rogers. Among them there is a *Cyathophylloid coral;* and none similar character is known before the *Petraia* of the Tren- n limestone; also species referred to *Chætetes*, *Stromatopora* (or *tromatocerium*), *Stictopora*, and *Euomphalus*. In its great thickness the .mestone differs vastly from that of the Calciferous beds of the Quebec group, and has its only counterpart in the Appalachian ·egion in the limestones of the Trenton period in Pennsylvania, which are nearly 6000 feet thick. Admitting this age for the limestones, the Green Mountain region did not become dry land until the close of either the Trenton or Hudson period.

Besides an emergence of the western part of the Green Mountain region at the close of the Lower Silurian, there probably also occurred the metamorphism of its rocks, making the shales and earthy limestones into hard slates and crystalline limestones, to be afterwards overlaid unconformably by later beds. It was probably at this time that the Stockbridge Eolian limestone became a statuary marble and its fossils were almost entirely obliterated. In the same operation, the rocky crust may have received that stiffening which made it a part of the *permanent* dry land, like the adjoining Azoic, and in consequence of which a district over which a subsidence of many thousands of feet took place in the Lower Silurian (p. 176) participated but little in the later Appalachian movements.

The Ottawa basin and the subsiding area of Keweenaw Point on Lake Superior also became comparatively stable before the Upper Silurian era began (pp. 199, 228).

In a few places there were dislocations of the strata after the close of the Lower Silurian, and again others before the Coal period. These are mentioned on pp. 227, 320. But in general the strata from the bottom of the Silurian to the top of the Carboniferous make an unbroken series, with no unconformability except the slight want of parallelism the great oscillations at times occasioned (p. 320). The great extent of the series, and the vast length of time occupied by those passing ages, make this exemption from great disturbances a subject of profound importance in American geological history.

4. *Direction of oscillations.*—The direction of the great oscillations of the continent may be learned from the course of the region along which, through the successive periods, the greatest amount of change of level took place. One such region is the Appalachian, in which the subsidence, as has been shown, amounted in some

parts to seven miles or more, while parallel with it in the *Interior basin* the average was comparatively small. The review of the limits of the successive formations, on p. 379, shows that even the minor changes took place under the influence of oscillations having this general course.

The Lower Silurian uplift from Cincinnati to Tennessee conforms to this system. In accordance also with it, the Coal measures in Pennsylvania, to the top of the Pittsburg series, were elevated so that their marshes became dry before the higher beds were laid down; and these upper beds, with the whole region west to the Mississippi, before the Permian (p. 371).

The Appalachian region, including from the Gulf of St. Lawrence to Alabama, lies parallel with one great branch of the Azoic dry land, C C, on map, p. 136, and also with the Atlantic Ocean. The Appalachian oscillations therefore conformed in direction with one of the two Azoic systems (p. 147): they were but a continuation of the series that prevailed while the Azoic age was in progress.

With regard to the region west of the Azoic, our information is yet scanty: sufficient, however, is known to make it apparent that the increase of dry land was from the Azoic to the southwest, or corresponding to oscillations parallel to the Rocky Mountains. The direct effect of such oscillations is manifest in the Illinois uplifts preceding the Coal measures, for they are parallel to the Rocky Mountain chain and the Pacific coast-line. This, then, was a second grand direction of oscillations. It was parallel with the northwestern branch of the Azoic, B B, on map, p. 136, and corresponded to the second of the two series that prevailed during the Azoic age.

It is hence apparent that, whatever the forces at work in Azoic time, they continued to act in the same general direction throughout the Palæozoic. The action of the two systems of forces together evidently produced the great amount of subsidence adjoining the Canada Azoic, where the thick deposits of the Huronian and Potsdam periods were formed, and where finally the basins of the great lakes were made. These, and nearly all the lakes of North America, lie near the limit between the oscillating part of the continent and the stable Azoic.

5. *Cotemporaneous movements in the American and European continents.*— The fact that the continent of Europe was above the ocean, and in that condition which was characteristic of the Coal period, at the same time with North America, shows a cotemporaneousness in the oscillations of the crust on the opposite sides of the Atlantic Ocean. This concordance will be better apprehended when it is

considered that the land must have been but little elevated, and quite uniformly so,—enough to drain the great salt marshes of their salt, and not so high as to turn them into dry fields. It was not sufficient that there should be land and Carboniferous vegetation; for without the wet, swampy lands—wet with fresh waters, and very wide in extent—the great accumulations of vegetation and immense coal fields would not have been made.

There is a similarity between the continents, also, in the character of the oscillations which occurred in the course of the Carboniferous period, which submerged the land after material for a coal bed had accumulated, and buried it for long keeping beneath sandstones and shales, and then brought it again to the surface for renewed verdure and another coal bed; and so on in many successions.

The Millstone grit, which preceded the Coal measures in Europe as well as America, is evidence of a degree of correspondence in that upward movement of the continents through the waves which ushered in the epoch of the Coal Measures; and the prevalence and wide distribution of the limestone of the Subcarboniferous period, which next preceded, mark another cotemporaneous movement,—a very general submergence preceding the emergence just alluded to. Moreover, in both continents, some thin coal beds were formed in the Subcarboniferous period.

Contrast between America and Europe.—While the two continents were at times concordant in their general movement, there was apparently a contrast during the Coal period in the moisture of the two, which may in part, at least, be attributed to climate. This is apparent in the vastly larger coal fields of America. Guyot has called America the *forest-continent*, a character it now bears because of its moist climate, or more abundant rains; and it is probable that it presented this peculiarity with the first appearance of vegetation over its surface.

IV. Life.

1. *System of progress.*—The Animal kingdom began with Radiates, Mollusks, and water Articulates; included Fishes, the lower Vertebrates, in the Devonian; and Reptiles in the Carboniferous age. With each period the progress was upward towards a fuller and higher display of the system of life.

It is important to observe, in this connection, that the length of the Age of Mollusks, or Silurian age, as shown on p. 386, was three or four times that of either the Devonian or the Carboniferous. This fact, in connection with

the abundance of the remains of fishes in the Devonian, makes their absence from the American Silurian, and from all the foreign below the Upper Ludlow beds, the more striking, and adds force to the conclusion that no fishes existed during that era. And the same holds true with regard to the absence of Reptiles from the Devonian age. On this ground alone, the supposed discovery by Pander of microscopic teeth of fishes, in the Russian Ungulite grit, of the Lower Silurian, with no knowledge of fish-relics elsewhere in the Silurian of America or Europe, would be reasonably questioned, were it not also proved that these so-called teeth were not ichthyic, but probably from the dental apparatus of Gasteropods.

It is an error, as the facts reviewed have shown, to suppose that the system of life commenced with the lowest forms, and reached always a higher grade with each new development. The following are some of the principles bearing on this progress which have been exemplified in Palæozoic history.

(1.) The earlier species were water species, and all of them marine.

Radiates and Mollusks the water Articulates, and Fishes the water Vertebrates, comprise all known species of animals until the close, or nearly the close, of the Devonian; and Sea-weeds all the plants to the close of the Silurian. In all divisions of the kingdoms of life the species made for the water are of inferior grade.

(2.) Many of the earlier types were of the kind called *comprehensive* types, as explained on pp. 203, 302.

Trilobites and the Ganoid fishes have been mentioned as examples. Other examples are—the *Labyrinthodont* Reptiles, which comprehended, along with the structure of the Amphibian, the scaly covering and some other peculiarities of the higher Reptiles; the large *Lepidodendrids* of the Coal era, which combined with the characteristics of the Cryptogams the foliage and general habit of the Conifers; the *Sigillarids*, which presented the general structure of the Conifers, with a habit and foliage that approximated them to Lepidodendrids; the *Calamites*, which possessed the habit of the Equiseta among Cryptogams, united, in some species at least, according to Brongniart, to a woody texture approaching that of the Sigillarids; and, in the early Silurian, the *Cystideans* among Radiates, which often had a want of radiate symmetry almost as great as characterizes Mollusks, and also some features of the later Echinoids joined with the essential structure of the Crinoids.

These comprehensive types, as is apparent in the examples, do not occupy a middle point between two of the general divisions of the Animal kingdom: on the contrary, they belong fundamentally to one, while partaking of some of the characteristics of the other.

They are called by Agassiz, who early recognized their nature, *synthetic* types,—a term not here used, as it implies that they correspond to a combination of what was before separate, rather than to one yet undivided. Guyot calls them *undivided* types.

(3.) The starting-point of a class or other division of the kingdoms of life was often from the top of its lower division and the bottom of the next above, or from an intermediate level between the two.

Dividing plants into Cryptogams and Phænogams; Crustaceans into Entomostracans, the lower, and Malacostracans, the higher group, as done by Cuvier; Reptiles into Amphibians and true Reptiles; Vertebrates into water-breathing and air-breathing: we observe that—

The earliest land-plants were the highest of the Cryptogams and the lower of the Phænogams (the Gymnosperms), together with groups that are intermediate and of the nature of the comprehensive types above described (see p. 333). The vegetable kingdom began with the lowest of its tribes, the Algæ, or Sea-weeds, and probably with the lowest of sea-weeds as far back as the Azoic age. But when terrestrial plants were to appear, there was not a series rising in grade from these sea-weeds up to the higher species of the land. On the contrary, the lower Cryptogams of the tribes of Mosses, Hepaticæ, and even the fresh-water Confervæ, were passed by, and the new species were those at the top of the order of Cryptogams, with others superior to the modern types of this order.

The early Crustaceans, Trilobites, belonged either to the top of the Entomostracans or to the bottom of the higher group, and presented features of both. (See p. 202.)

The earliest Reptiles were not the lowest of Amphibians; but along with some of the inferior species of this division there were *Labyrinthodonts*, a family above the true level of the Amphibians, together with *Lacertians*, and also *swimming Saurians*, species belonging to the inferior divisions of True Reptiles.

Vertebrates commenced, not with the lowest fishes, but with a group above the true level of the fish, in a type which included several characteristics of the higher class of Reptiles (p. 302).

The evidence in the rocks thus sustains the conclusion that many of the groups began, not with their lowest species,—that is, those at the bottom of the lower group,—but, on the contrary, with those at the top of the lower group and near the bottom of a higher, or from some intermediate point between the two. In this way a remarkable harmony was given to the fauna and flora of an age. The flora of the Carboniferous is a fine example of this principle.

This harmony was sometimes further promoted by adding to one

type peculiarities of another, where this intermediate position of the species is not apparent. Thus, in the age of Mollusks, perhaps the most abundant form of Crustacean was the Ostracoid, which had a *bivalve shell* like the Mollusks.

None of the examples of comprehensive or undivided types have been drawn from Mollusks. They are, in fact, less marked in this sub-kingdom, because all its several grand divisions were represented in the first appearance of animal life, even to the highest, that of Cephalopods. It started as an unfolded type. There were even many of the minor subdivisions in the early Silurian. The siphonated Conchifers—the higher group—commenced with the Potsdam period (p. 191), if the genus Conocardium is rightly referred to the Cardium family; Pteropods probably passed their period of culmination in the Silurian; Brachiopods, theirs, in the later Palæozoic; and Cephalopods, theirs, in the Mesozoic. Gasteropods were less well represented than the other tribes, and these have their fullest display in the present age. The Cephalopods, however, may properly rank among comprehensive types; they combine in the Molluscan structure the large perfect eyes and other senses of the Vertebrates, and in some of them an internal bone, along with great activity and strength,—characteristics not typical of Mollusks. They were the princes of the Palæozoic world until the appearance of Vertebrates,—the type they partly foreshadowed.

(4.) The *comprehensive* types of early time become nearly or quite extinct with the progress of the system of life, while the types which were foreshadowed by them or partly comprehended in them are long afterwards perpetuated.

Trilobites, Lepidodendrids, Sigillarids, Calamites, become extinct in the Carboniferous age, Cystideans in the Lower Devonian. It will be found that the Ganoid fishes and Labyrinthodonts are also examples under this law. The small Lycopodia of our woods are the only representatives of the great Lepidodendrids of the Coal era, while ferns, the typical Acrogens, and Conifers, the typical Gymnosperms, are yet abundant in species. The Trilobites were accompanied by typical Entomostracans, the Eurypteri and related species, before the close of the Silurian; and, when disappearing in the Carboniferous age, the Tetradecapods, foreshadowed in the Trilobites, were already in the waters.

2. *Exterminations.*—At the close of each period of the Palæozoic ages there was a general extermination of the living species, which was nearly, and sometimes quite, complete. Again, as each epoch terminated there was an extermination of life, but in most cases much less general. With the transitions between strata of different kinds in the course of an epoch there were usually some exterminations; and even in the passage from layer to layer the extinction of one or more species took place. In a corresponding manner

there were often one or more new species with each new kind of layer, and generally several with each change in the strata; while many appeared with the opening of an epoch, and a whole fauna, nearly, with the commencement of a period. There is, then, this grand principle:—

Creations and extinctions of species were going on through the whole course of the history, instead of being confined to particular points of time; but at the close of long periods and epochs there were nearly universal extinctions, followed by abundant creations.

The means by which exterminations may have been produced have been often alluded to in the preceding pages, and need here be recapitulated only in brief,—namely:

For marine species, (1) a sinking of the sea-bottom, carrying the species below the depth at which they flourish; or (2) an elevation of it so as to make it dry land, on which, of course, all the marine life would become extinct; (3) a change by variation of level or raising of barriers sufficient to change clear and pure waters into waters full of sediment, or expose them to an influx of sedimentary material, and the reverse; (4) a similar change, sufficient to turn the salt-water sea into a fresh-water area. Besides these, there may be mentioned submarine igneous action heating the waters. With such causes for exterminations, it is intelligible that the extinction of a fauna might be nearly complete in one area and not so in another, and that where such extinctions were partial there might be in some cases a partial repeopling of a district from that one in which there were surviving species.

3. *Extinction of whole tribes, families, or genera of species.*—The characteristic tribes of land-plants in the Coal era, and those that became extinct, have been mentioned on p. 333.

The races of animals that were most prominent in giving a special character to the Palæozoic fauna were as follow:—

Among *Radiates*, Crinoids and Cyathophylloid Corals; among *Mollusks*, Brachiopods; among *Articulates*, Trilobites; among *Vertebrates*, the vertebrate-tailed Ganoid fishes. Of these, the groups of Cyathophylloid Corals and Trilobites become extinct with the close of the Palæozoic, and the vertebrate-tailed Ganoids very nearly so; and Crinoids and Brachiopods lose their pre-eminence in numbers of species and individuals in their respective subkingdoms.

The following are a few other examples of the extinction of prominent Palæozoic groups:—

Graptolites, which culminated in the Lower Silurian and ended in the Clinton epoch of the Upper Silurian; *Cystideans*, which culmi-

nated also in the Lower Silurian and became extinct in the beginning of the Devonian; *Goniatites*, which began in the Hamilton period of the Devonian and disappeared with the Carboniferous age. Many other instances are given in the table beyond. The causes of such extinctions were connected with a higher principle than that of mere physical catastrophe.

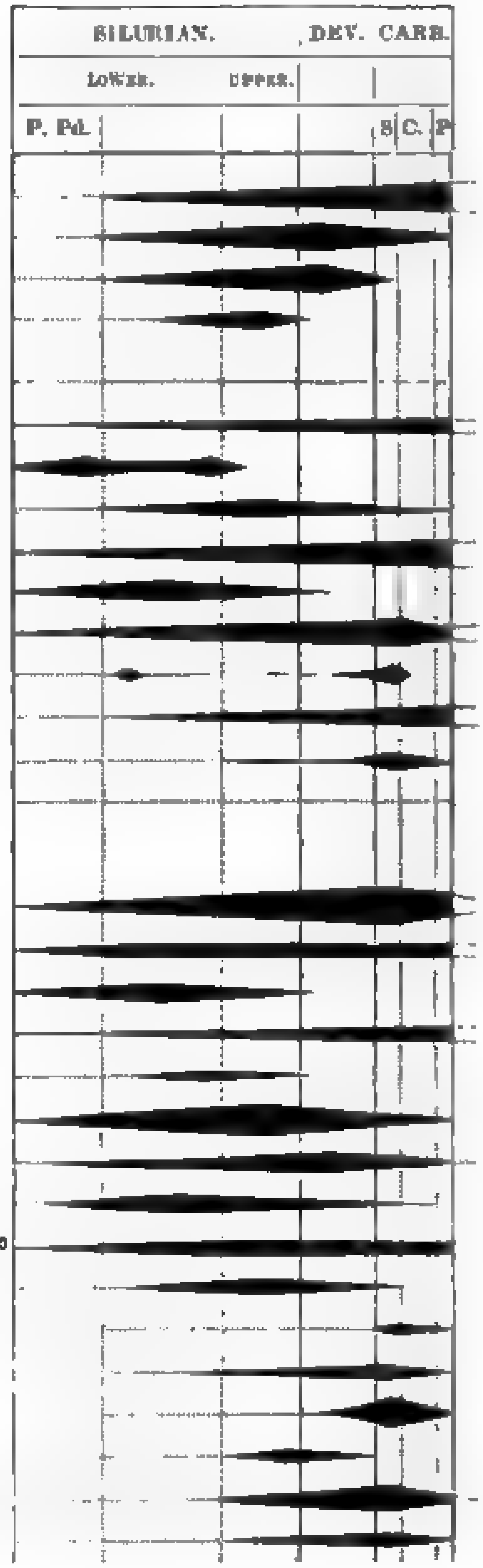
The following table presents to the eye the history of many of the genera, families, and tribes of Palæozoic species, showing by means of the narrow dark areas the time of their commencement; the time of their culmination (by the greatest breadth of the area); and the time of their extinction in the course of the Palæozoic ages, or the fact of their continuing to survive in after-time. Thus, opposite the word *Polyps*, the area commences near the beginning of the Silurian, and increases through the Palæozoic, and does not terminate there, as they exist afterwards; the *Cyathophylloid* Corals begin with the Lower Silurian, have their maximum in the Devonian, and terminate in the Carboniferous; the *Astræa*, *Madrepora*, and *Caryophyllia* families of corals (which include most modern reef-making species) do not commence until *after* the Palæozoic, and hence, as there are no Palæozoic species, there is a dotted line opposite, without an area. At the top of the columns, P. Pd. stands for Potsdam or Primordial Period; and S., C., P., for Subcarboniferous, Carboniferous, and Permian.

4. *Genera of the present time dating from the Palæozoic age.*—The number of lines connecting the past with the present is considerably increased in the Carboniferous age. These lines are, however, only long-lived genera, not species. The following are those which appear to be determined with a good degree of certainty:—

Lingula, Discina, Crania, Nautilus, Rhynchonella, Terebratula, Ostrea, Avicula, Pinna, Pecten, Solemya, Leda, Nucula, Dentalium, Chiton, Pupa. They are all Molluscan. The first five commenced in the Lower Silurian. It is a remarkable fact that there are no Radiate genera in this list.

Besides the above, the genera *Arca*, *Lima*, and *Astarte* have been referred to the Palæozoic; but the species probably belong to other genera. There are no genera of Articulates, unless it be the genus *Spirorbis*, about which there is doubt. Some of the Palæozoic genera of Ostracoids have modern names, but there are no means of proving that they are identical in type with those of modern seas.

There are modern genera of Rhizopods in the Palæozoic, and probably also of Diatoms; and the number of such genera among these protozoan and protophyte forms will probably be greatly increased when further investigated.



RADIATES.

Polyps

Cyathophyllum Family

Favosites (Acalephs?)

Halysites (Acalephs?)

Astræa, Madrepora, and Caryophyllia Families

Acalephs

* Graptolites

Chætetes

Echinoderms

Cystideans

Crinideans

Blastoids (Pentremites, etc.)

Star-fishes

Palæchinoids (including Archæocidaris)

Cidarids, Spatangids, etc.

MOLLUSKS.

Brachiopods

Lingula Family, gen. Lingula

Obolus, Obolella.

Discina Family, gen. Discina

Siphonotreta

Orthis Family, gen. Orthis

Leptæna

Strophomena

Rhynchonella Fam. gen. Rhynchonella, etc

Pentamerus

Camarophoria

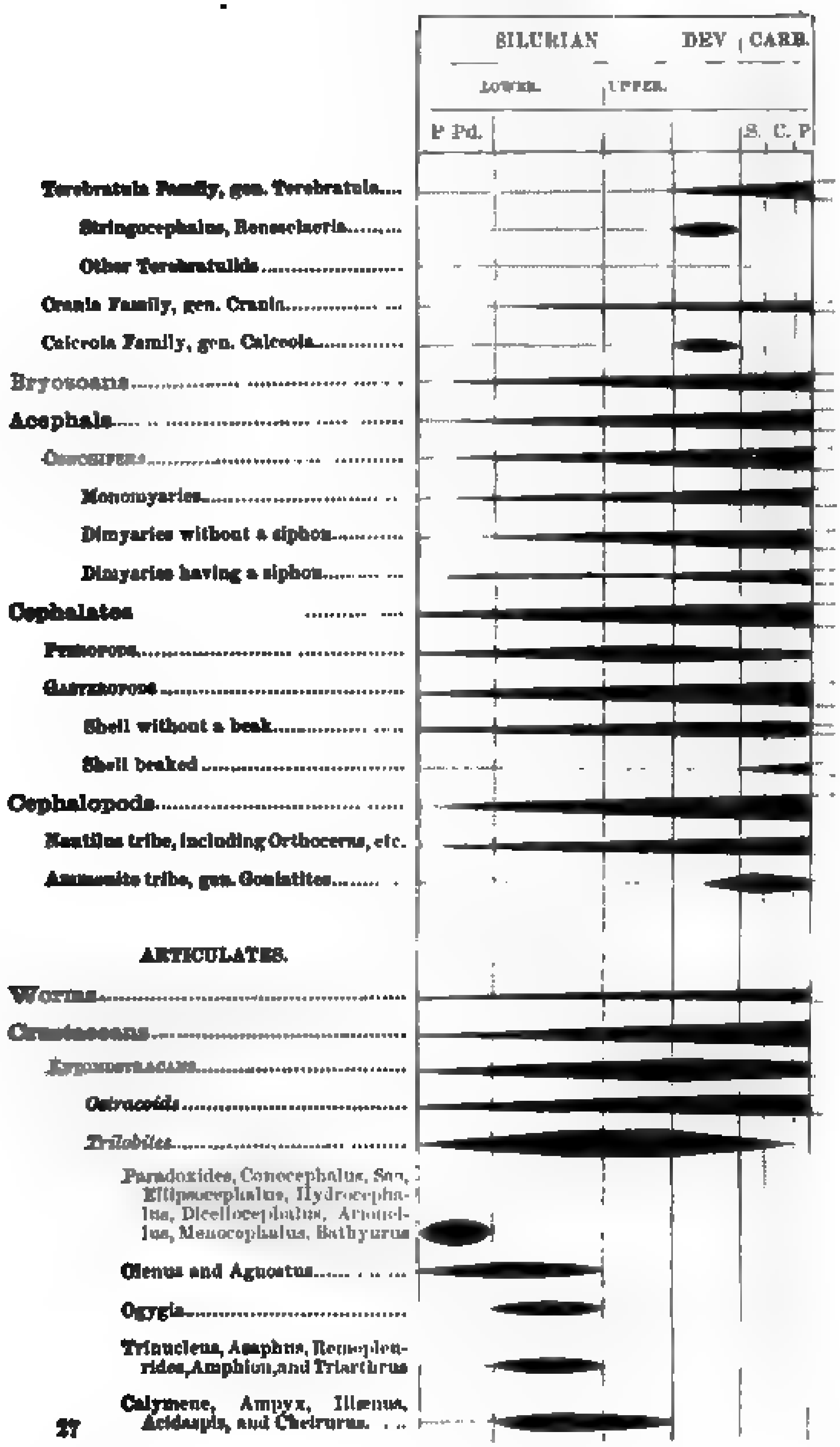
Productus Family, gen. Chonetes

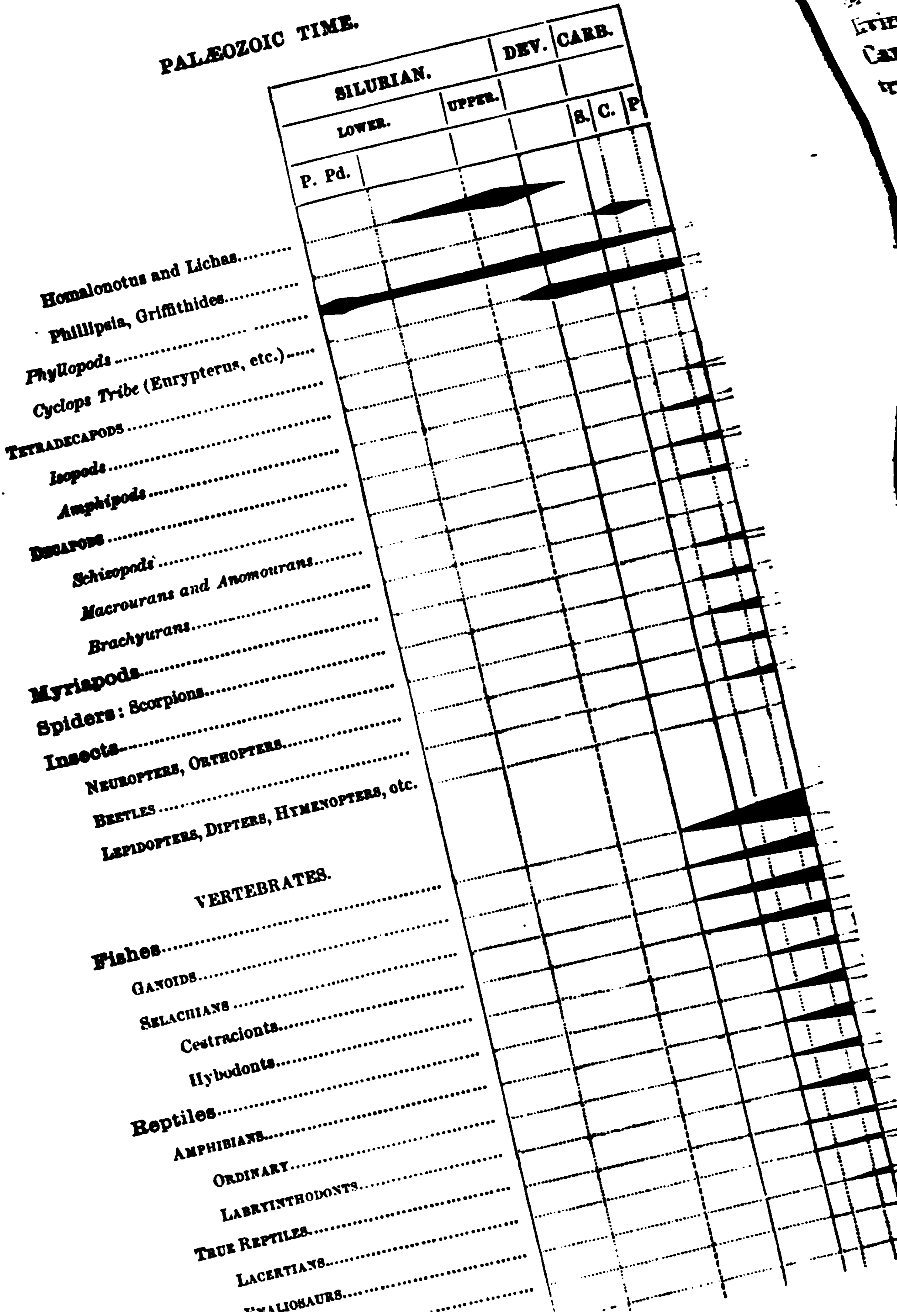
Productus

Spirifer Family, gen. Atrypa

Spirifer

Athyris


SILURIAN
DEV
CARB.
LOWER.
UPPER.
P. Pd.
S. C. P.
Terebratula Family, gen. Terebratula....
Stringocephalus, Rensselaeria..........
Other Terebratulids.........................
Crania Family, gen. Crania.................
Calceola Family, gen. Calceola.............
Bryozoans.......................................
Acephals...
Conchifers.......................................
Monomyaries...................................
Dimyaries without a siphon...........
Dimyaries having a siphon.............
Cephalates ....
Pteropods.......................................
Gasteropods...................................
Shell without a beak.................
Shell beaked ....
Cephalopods.....................................
Nautilus tribe, including Orthoceras, etc.
Ammonite tribe, gen. Goniatites........
ARTICULATES.
Worms..
Crustaceans.....................................
Entomostracans.................................
Ostracoids.....................................
Trilobites......................................
Paradoxides, Conocephalus, Sao, Ellipsocephalus, Hydrocephalus, Dicellocephalus, Arionellus, Menocephalus, Bathyurus
Olenus and Agnostus.............
Ogygia.....................................
Trinucleus, Asaphus, Remopleurides, Amphion, and Triarthrus
Calymene, Ampyx, Illænus, Acidaspis, and Cheirurus. . . .


PALÆOZOIC TIME.
SILURIAN.
DEV.
CARB.
LOWER.
UPPER.
S.
C.
P
P. Pd.
Homalonotus and Lichas
Phillipsia, Griffithides
Phyllopods
Cyclops Tribe (Eurypterus, etc.)
Tetradecapods
Isopods
Amphipods
Decapods
Schizopods
Macrourans and Anomourans
Brachyurans
Myriapods
Spiders: Scorpions
Insects
Neuropters, Orthopters
Beetles
Lepidopters, Dipters, Hymenopters, etc.
VERTEBRATES.
Fishes
Ganoids
Selachians
Cestracionts
Hybodonts
Reptiles
Amphibians
Ordinary
Labyrinthodonts
True Reptiles
Lacertians

5. *Complete extermination of the Carboniferous life.*—At the close of the Carboniferous age there was a complete extermination of all living species. No plant or animal of America continues from the Carboniferous into the Reptilian age; and the same is probably true for Europe.

DISTURBANCES CLOSING PALÆOZOIC TIME.

1. AMERICAN.

After the long ages of comparative quiet, when the successive Palæozoic formations were in slow progress, and finally the rock-foundation of the continent east of the Rocky Mountains was nearly completed, a change of great magnitude began, which involved the Appalachian region with the continental border adjoining, and well merits the title of the Appalachian revolution.

The evidences of the change may be treated of under two heads:—1, disturbances of the strata; 2, alteration or metamorphism, due, partly at least, to heat.

1. Disturbances of the strata.

1. **Flexures.**—The Coal measures of Pennsylvania, Rhode Island, and Nova Scotia, which were originally spread out in horizontal beds of great extent, are now tilted at various angles, or rise into folds, and the strata are broken and faulted on a grand scale. The folds vary from a few rods to one hundred or more miles in breadth, and are in many successions over the region, wave succeeding wave. Moreover, not only the Coal measures, but the Devonian and Silurian, and in some regions, at least, part of the Azoic beds beneath, are involved together in this majestic system of displacements. The following facts on this subject are mainly from the Memoirs and Geological Reports of the Professors Rogers.

Fig. 619.

Section of the Coal measures, near Nesquehoning, Pa.

The general character of the flexures is illustrated in the annexed sections. Fig. 619 (by Taylor) is from the anthracite strata of the

Mauch Chunk region, Pennsylvania. The great coal bed is folded and doubled on itself, and part of the enclosing strata are nearly vertical. In fig. 620 (by Rogers), from Trevorton, Pa., the folding is of a more gentle kind; eight coal seams are contained in this

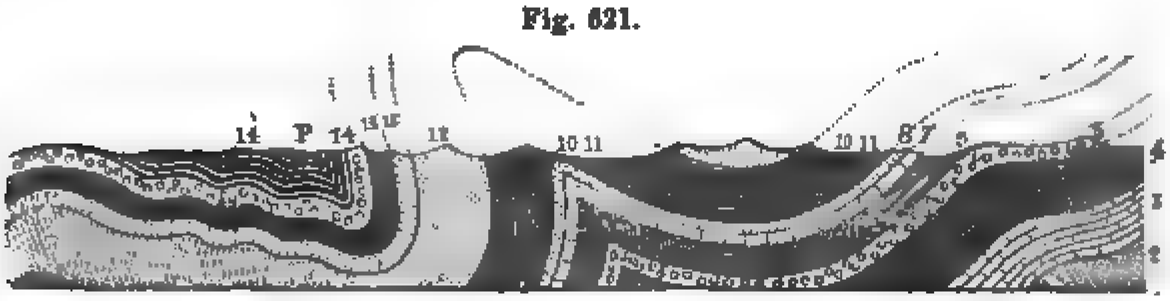
Fig. 620.

Section of the Coal measures half a mile west of Trevorton Gap, Pa.

section, each of the dark lines representing one. These are examples of the condition of the whole anthracite region. The patches into which it is divided, as shown on the map, p. 323, illustrate other effects of the foldings; for the whole, in all probability, was originally one great area, continuous with that of western Pennsylvania.

The sections represented in figs. 621, 622, illustrate the flexures of the Palæozoic rocks, showing that the whole participated in

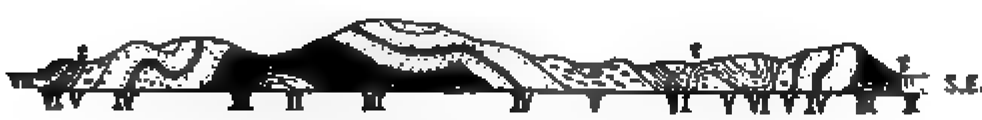
Fig. 621.



Section on the Schuylkill, Pa.; P. Pottsville, on the Coal measures.

the system. Fig. 621 (by Lesley) is a section from the Schuylkill along by Pottsville: the formations included in it embrace

Fig. 622.



Section from the Great North to the Little North Mountain through Bore Springs, Va.; *t*, *t*, position of thermal springs.

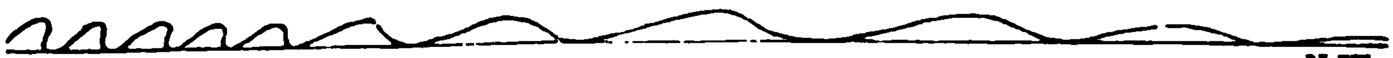
from the Potsdam sandstone (2) to the Coal formation (14); the numbers indicate the formations. The section in fig. 622 (by Rogers) extends from the Great North to the Little North Mountain through the Bore Springs, in Virginia: it has been partly ex-

plained on pp. 104, 107. The formations are numbered—II. the Calciferous; III. Trenton; IV. Hudson River; V. Oneida; VI. Clinton and Lower Helderberg; VII. Oriskany sandstone and Cauda-Galli grit.

The mountains of Pennsylvania as well as Virginia are full of such sections. In fact, they present the common features of the Appalachians from Alabama to New Jersey. It is here obvious that not only the Coal measures but the whole Palæozoic has been forced by some agency out of its originally horizontal condition into this contorted state. The folds were mountains themselves in extent; but through the extensive denudation to which they have since been subjected they have been worn off and variously modified in external shape, until now, as explained on page 108, it is often extremely difficult to trace out the original connections.

On the east, or towards the ocean, the folds are so pressed together, and their tops so completely removed, that often only a series of *southeasterly dips* remain (p. 107). Beyond these, the folds are more separated, though still abrupt; farther west, they diminish in boldness, until they become gentle undulations; yet there is often a sudden transition to these gentler bendings along lines of great faults. The following outline represents this general feature of the successive folds from the southeast or ocean side across the mountains to the northwest. (Rogers.) It should not be inferred from this figure that the folds have the regularity here given; the preceding figures show that this is very far from the truth. It would also be an error to suppose that the number of folds is uniform through the length of the Appalachians. On the contrary, all along their course there are folds rising and others disappearing;

Fig. 623.



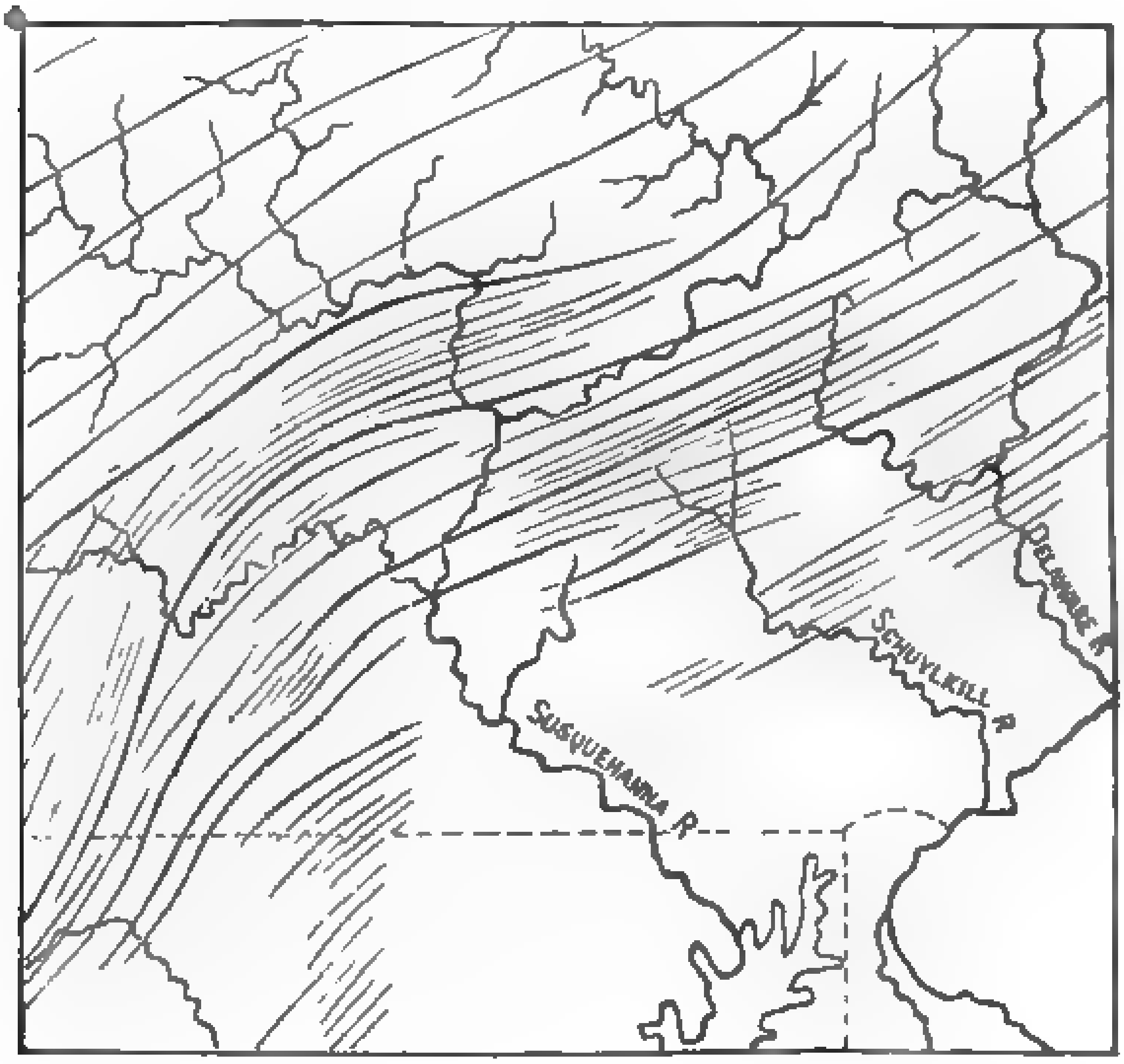
S.E. N.W.

Ideal section from the S.E. to the N.W. across the Appalachians.

they may continue on for a few miles or scores of miles, and some for much greater distances, and then gradually disappear, while others, more to the east or west, take their places. Thus, the Appalachian chain is made up of a complexity of flexures following a common direction. This character is well shown in fig. 624,—a map prepared for this work by J. P. Lesley, who, in connection with other assistants in the Geological Survey of Pennsylvania, has done much towards working out the facts here presented. It gives a general view of the direction and number of the folds through Pennsylvania. Each line stands for the axis of a flexure. Without

claiming absolute accuracy, it gives a correct general idea of the number and positions of the folds in this part of the Appalachian region.

Fig. 624.



Map of Pennsylvania, showing the positions of the axes of the folds in the strata.

The following are some of the most important facts established with regard to these Appalachian flexures:—

1. They occupy the whole *Appalachian* and *Eastern-border regions* of the continent nearly or quite to the Atlantic Ocean.

2. They are parallel with the general course of the mountains, and nearly with the Atlantic coast.

3. They are most crowded and most abrupt over the part of the regions which is towards the ocean,—that is, the southeast side (figs. 622, 623).

4. The steepest slope of a fold is that which faces the northwest, or away from the ocean (figs. 621–623).

5. They are in numerous ranges; but, while some are of very great length, there is in general a commingling of shorter flexures, and often they are in groups of overlapping lines (fig. 624), as explained, with reference to the arrangement of the parts of mountains, on pp. 19 and 20.

6. Although many of the folds were like mountains in dimensions, they have been so worn and removed by denuding waters—either those of the ocean or rivers, or of both—that the higher parts of the folds do not generally form the summits of existing elevations. The fissures of the broken mountains would have been deepest and most numerous in the axes of the folds; and hence denudation has been most destructive along the more elevated portions.

7. Over the more eastern part of the Appalachian region and the Continental border the folds were generally so pressed over to the northwest that their tops projected westward, and, consequently, both the southeast and northwest sides have a common dip to the southeast (fig. 623); and, as these regions have been since denuded, nothing remains in many parts but a series of strata dipping all alike to the southeast. (See p. 107.)

A uniform series of southeast dips over such a region is evidence that the strata correspond to a number of decapitated folds.

2. **Faults.**—Besides the remarkable plication of the earth's crust in this Appalachian revolution, numberless fractures and faults or dislocations occurred over the whole region, as was natural under the contortions and uplifts in progress. Some of the faultings were of great extent, lifting the rocks on one side of the line of fracture 5000 or 10,000 feet above the level on the other side. The faults mentioned on p. 198 are of this character, and part of the series there alluded to was probably made at this time. There is one of these great faults west of the Cumberland Mountains, in eastern Tennessee, well shown in the map and sections by Safford. In southwestern Virginia there are faults, according to Rogers, of seven or eight thousand feet. One remarkable line of this kind extends along the western margin of the Great Valley of Virginia, throughout the chief part of its length, along by the ridge (on the northwest side of the valley) named in its different parts the Little North Mountain, North Mountain, and Brushy Ridge. In some parts the Lower Silurian limestone is brought into conjunction with beds but little below the Subcarboniferous limestone, so that there is a transition from the lower strata to the upper in simply crossing the fault. In some places there is an inversion of the strata, so that a bed of semibituminous coal of the upper beds is found under the

Lower Silurian limestone and conformable to it in dip. This fault continues on for eighty miles. (W. B. & H. D. Rogers.)

Several such examples might be cited from Pennsylvania as well as Virginia. One occurs near Chambersburg, Pa., and is thus described by Lesley in his "Manual of Coal and its Topography" (p. 147). "The western side of the anticlinal Cove canoe has been cut off and carried down at least twenty thousand feet into the abyss, along a fracture twenty miles in length; the eastern side must have stood high enough in the air to make a Hindoo Koosh; and all the materials must have been swept into the Atlantic by the denuding flood. The evidence of this is of the simplest order and patent to every eye. The highest portions of the Upper Silurian wall against the lowest portions of the Lower Silurian. The thickness of the rocks between is, of course, the exact measure of the downthrow, which is therefore twenty times as great as the celebrated Pennine Fault in England. Yet a man can stand astride across the crevice, with one foot on Trenton limestone and the other on Hamilton slates, and put his hand upon some great fragments of Shawangunk grit, caught as it was falling down the chasm, held fast in its jaws as it closed, and revealed by the merest accident of lying suspended in the crack just where the plane of denudation happened to cut it."

Passing now farther north, to New England, we find the same system of flexures as occurs to the south. The rocks are generally crystalline, and it is not at first obvious that they were ever Palæozoic strata and have been metamorphosed into their present condition. But this is proved by the portions of the strata which remain undisguised by the alteration.

The western part and summit of the Green Mountains have already been shown to be altered Lower Silurian, and fossils have been referred to that prove it (p. 392).

Again, Devonian (Upper Helderberg) rocks have been identified by their fossils in northern Vermont and at Bernardston in Massachusetts. It is probable that from the former position a line of Devonian rocks extends south through eastern Vermont; and the Bernardston beds are supposed to be part of the same formation, but on the opposite side of an anticlinal. (Hitchcock.)

Between Worcester, Mass., and Newport, R.I., the Coal formation occurs with its usual fossil plants, and conglomerates of the Coal measures stretch on towards Boston (p. 325).

South of Boston, at Braintree, fossils of the Potsdam period have been found (p. 184). On the northern margin of New England the rocks graduate into those of British America, which are

hardly at all altered, and which are Silurian, Devonian, and Carboniferous in age.

There is, therefore, abundant reason for the inference that New England is made up of Palæozoic rocks. The White Mountains of New Hampshire are now believed to be formed of altered Devonian strata. The gneiss quarries of Haddam, on the Connecticut, probably consist either of Carboniferous or Upper Devonian deposits; for the graphite on the slabs sometimes has the form of the stems of plants: one of them, fourteen inches long and one to two wide, now in the Yale cabinet, is too plainly vegetable to be doubted, though now deprived of its original markings.

The conformity to the Appalachian system appears in,—

1. A general parallelism of the outcrops to the Green Mountains, the bands of rock marked on a geological map all having this common course.

2. A general prevalence of east-southeast dips over New England, showing that there are here a series of decapitated folds, as well as over eastern Pennsylvania and Virginia.

3. The steepest side of the fold being the western, as follows from the fact last mentioned.

4. The flexures, fractures, and dislocations of the coal beds of Rhode Island and the neighboring region in Massachusetts.

Western New England received a part at least of its flexures before the Upper Silurian era (p. 392). The rest probably dates its upturning from the time of disturbance here considered. The fact that the Coal formation is among the folds proves this for a large part of New England. Between these beds and the Devonian of eastern Vermont the rocks are probably either Carboniferous or Devonian; and the whole probably participated in these changes.

In Nova Scotia and New Brunswick there are other examples of folded Carboniferous, Devonian, and Silurian strata, sustaining the conclusions deduced from the regions to the southwest.

Thus, the whole Continental border from Alabama to Newfoundland participated in these grand movements. The facts mentioned do not prove that the production of the flexures in the strata was necessarily accompanied by the emergence of the Appalachian region.

2. Alterations of rocks.

The alterations which the rocks underwent at the time of these disturbances are as follow:—

1. *Consolidation.*—Strata were consolidated; for the rocks of the

Coal measures, the conglomerates and sandstones especially, are often very hard and siliceous where the beds have been most folded or disturbed.

2. *Debituminization of Coal.*—The coal is without bitumen or a true *anthracite* where the rocks are most disturbed; and going westward, into regions of less disturbance, the proportion of bitumen or volatile substances increases quite regularly (Rogers). It appears as if the debituminization of the coal had taken place from some cause connected with the uplifting. In Rhode Island the effects are still more marked, the coal being altered not simply to an excessively hard anthracite, but in part to graphite.

3. *Crystallization or metamorphism.*—In the regions where the folds are pressed together most crowdedly and the evidences of disturbance are extreme, as over New England, and the Eastern border south of New York, the rocks are often crystallized, being granite, gneiss, mica schist, and the like. There, also, granitic and mineral veins abound.

3. Some characteristics of the force engaged.

The cause of this extensive series of flexures had, obviously, the following among its characteristics:—

1. *The force acted at right angles to the course of the flexures, and, therefore, to the general direction of the Atlantic coast.*—It is obvious, without explanation, that only force from this direction could have produced the result. The process is easily imitated with paper or cloth.

2. *The force acted from the direction of the ocean.*—For all the effects—the flexing and metamorphic—are most intense on the oceanic side; they fade out towards the interior.

3. *The force was vast in amount.*

If any one doubt, he may satisfy himself by working out the following problem:—

(*a.*) Given the thickness of the rocks at 30,000 to 40,000 feet (the depth of the Palæozoic in the Appalachians), part of the beds (if not all) already stiff and solid,—for the limestones are as solid when first formed as ever afterward. (It is probable that the whole earth's crust was involved, giving a thickness of 100,000 feet or more.)

(*b.*) Length of region acted upon, 1500 miles; breadth, 100 to 300 miles.

(*c.*) Required to press the beds, over this region, from top to bottom, into a series of great flexures such as has been described, and to force them on to the northwest until the tops of many of the flexures shall overhang their bases to the westward, and farther until numbers of them shall close up into a solid body or mass: span of flexures, mostly from 1 mile to 50; rise, mostly from 100 to 5000 feet.

Whoever tries to work the problem will emerge from his calculation satisfied that the force was vast.

4. *The force was slow in action and long continued.*—That the movement must have been slow in progress, the flexures forming by a movement of a few feet or yards in a century, continued through a long time, is evident from the regularity of the stratification notwithstanding the majestic system of foldings; for there is no chaos: the beds remain in their old order, only bent into arches and bold flexures. The brittle rock experienced the force so gradually that it yielded with little fracture, except along the axes of the folds, where the strain was greatest. The folds were sometimes pressed over until their tops projected westward over their bases,—which could have been done only by a force acting with extreme slowness. There may have been sudden starts, and earthquakes beyond modern experience, but the general course of progress must have been quiet.

5. *Heat.*—Several thermal springs exist in Virginia, situated, according to Rogers, along the axes of the Appalachian folds, as if some traces of the heat in action still remained.

4. Identity of the force with that causing movements in earlier time.

The force was the same in kind, and also in direction, judging from the identity of results, with that which produced the flexures and other changes that closed the Azoic age (p. 143); the same that caused the oscillations through the progressing Palæozoic ages required for the completion of the succession of rocks; the same that occasioned the deep subsidences along the Appalachian region.

The Atlantic coast along New England varies much from its general course. But this is only a repetition of an Azoic fact. The line has a parallel in the Green Mountains with the westward bend through New Jersey and Pennsylvania, and a still earlier parallel in the outline of the New York Azoic.

When the Appalachian subsidences were about to cease, then began the new movement that flexed and stiffened the rocks of the Atlantic border.

Although there is no proof in the flexures, or the metamorphism, of any emergence of the strata from the ocean during their progress, there is sure evidence that when the revolution ceased it left the Appalachian chain with at least its present elevation. The evidence of this final result of the moving forces is afforded by the strata of Mesozoic time, which come next under consideration.

2. DISTURBANCES IN FOREIGN COUNTRIES.

The disturbances through the course of the Palæozoic ages in Europe appear to have been more numerous and diversified than in America. But they were inferior in extent to those that attended its close. Murchison remarks that the close of the Carboniferous period was specially marked by disturbances and upliftings. He states that it was then "that the coal strata and their antecedent formations were very generally broken up and thrown, by grand upheavals, into separate basins, which were fractured by numberless powerful dislocations." In the north of England, as first shown by Sedgwick, and also near Bristol, and in the southeastern part of the Coal measures of South Wales, there is distinct unconformability between the Carboniferous and lowest Permian. Elie de Beaumont has named this system of dislocations *the System of the North of England.* Between Derby and the frontier of Scotland the mountain-axis is of this date, and trends between north and north-northwest; the region is remarkable for its immense faults. The great dislocations of North Wales may be of the same epoch.

Yet, while it is manifest that the period between the close of the Carboniferous and the Trias was one of enormous disturbances, it is not always clear to what time in this interval particular uplifts should be referred. In the Dudley coal field, the Permian beds, according to Murchison, are conformable to the Carboniferous; but at the close of the Permian (or at least before the middle of the Trias) there were great dislocations. In other coal regions, as those of France and Belgium, and of Bohemia about Prague, there is other evidence of physical changes in the absence of Permian beds, while also, in many places, the beds of these coal regions are much contorted. De Beaumont's *System of the Netherlands* includes dislocations of Permian beds along the foot of the Hartz Mountains, and in Nassau and Saxony, which preceded the deposition of the Triassic. He distinguishes examples of this system of disturbances in France and some other parts of Europe, and also prominently in South Wales. To his *System of the Rhine* he refers dislocations and elevations of the Permian sandstone of the Vosges (grès de Vosges) along the mountains of the Vosges, the Black Forest, and the Odenwald, and shows that they antedate the Triassic period.

In Russia, as well as England, there are tracts where the Permian strata follow on after the Carboniferous without unconformability. It was in this closing part of the Palæozoic era, either

after the Carboniferous or Permian, that the rocks of the Urals were folded and crystallized; for Carboniferous rocks are flexed and altered in the same manner as in the Appalachians. The auriferous quartz veins probably date from this era.

TRANSITION FROM THE PALÆOZOIC TO THE MESOZOIC.

The transition from Palæozoic to Mesozoic time was strongly marked in Geological history,—unequalled, in fact, by any of earlier date after the Azoic revolution in which the Laurentian rocks were folded and crystallized, and by any in later ages, with the single exception of that from Mesozoic to Cenozoic time. The events which give it this prominence are:—

1. A thoroughly complete extermination of existing life.
2. An extinction of several great Palæozoic races, the decline of others, and a general change in the character of the life.
3. The extensive folding and crystallizing of Palæozoic formations in many regions.
4. The development of a number of prominent mountain-ranges, making new features in the earth's topography.
5. In North America, a great change in the scene of geological progress, so that the regions are no longer the *Eastern border*, the *Appalachian*, and the great *Interior Continental;* but, instead, the *Atlantic border*, the *Gulf border*, and the *Western Interior*, or interior west of the Mississippi. The Eastern Interior and the Appalachian regions no longer participate in the rock-making. The three new regions coalesce; the last is but a continuation of the Gulf region to the northwest over the area of the Rocky Mountains, which was still low or submerged; whether it communicated directly with the Pacific is not ascertained.

By the close of the Palæozoic, nine-tenths of all the rocks of the globe had been formed. During the epoch of revolution that followed, these beds, besides undergoing in many regions an extensive crystallization fitting them prospectively for the uses of art, were also supplied with mineral wealth. Much of the gold of the world comes originally from rocks which were metamorphosed and filled with veins at this time. The same is believed to be true of platinum and diamonds. None of the precious metals are yet known to occur in the crystalline Azoic. Some of the veins of tin, copper, and lead, and mines of topaz, emerald, and sapphire, are among the productions of this epoch of metamorphism.

Thus furnished, the world was prepared for another stage in its course of progress.

III. MESOZOIC TIME.

The Mesozoic or Medieval time in the Earth's history comprises a single age only,—the REPTILIAN.

REPTILIAN AGE.

The Age of Reptiles is especially remarkable as the era of the culmination and incipient decline of two great types in the Animal Kingdom, the *Reptilian* and *Molluscan*, and of one in the Vegetable Kingdom, the *Cycadean*. It is also remarkable as the era of the *first Mammals*,—the *first Birds*,—the *first* of the *Common* or *Osseous Fishes*,—and the *first Palms* and *Angiosperms* (p. 166).

The Age is divided into three periods. Beginning with the earliest, they are:—

1. The TRIASSIC PERIOD.
2. The JURASSIC PERIOD.
3. The CRETACEOUS OR CHALK PERIOD.

These periods are well defined in European Geology. But in North American the separation of the first and second has not yet in all regions been clearly made out.

TRIASSIC PERIOD (16).

The name *Triassic*, given to this period, alludes to a threefold division which this formation presents in Germany. This division is a local character, and unessential: it does not occur in other remote parts of Europe, or in England, and is not to be looked for in distant continents.

1. AMERICAN.

The formation referred to the Triassic in America may belong in part to the Jurassic period. It does not reach back into the Permian, because there are no Palæozoic forms among the plants or animals. It is also true that there are no species that are peculiarly Jurassic, while many of them correspond in character with those of the foreign Triassic.

I. Rocks: kinds and distribution.

The rocks are met with in two distinct regions:—1, in the *Atlantic border region*, between the Appalachians and the coast; 2, in the *Western Interior region*, over part of the slopes of the Rocky Mountains.

On the *Atlantic border* the beds occur in long narrow strips

parallel with the mountains or the coast-line, and occupy synclinal valleys formed in the course of the folding of the Appalachians. They lie unconformably on the folded crystalline rocks, and thus show that they are subsequent in age. On the map, page 133, the narrow areas are obliquely lined from the right to the left. One is situated in the Connecticut valley, and extends from New Haven to northern Massachusetts; others are distributed over the region between the lower Hudson (the Palisades) and the southern part of North Carolina.

The map of Pennsylvania on p. 323 shows the position of the area in that State, it being distinguished by the same oblique lining as on the general map. It takes the same westward bend with the Appalachians of the State, retaining that parallelism with the mountains which characterizes the areas elsewhere, and thus corresponding in direction with the synclinal valleys.

The rock is in general a red sandstone, passing in some places into a shale or conglomerate, and occasionally including beds of impure limestone. The brown building-stone of Newark, N.J., and Portland, Conn., often called *Freestone*, and much used in the city of New York and elsewhere, comes from this formation. Near Richmond, Va., and Deep River, in North Carolina, there are valuable beds of bituminous coal.

In many regions the layers of rock are covered with ripple-marks and raindrop-impressions, or penetrated with what were originally mud-cracks,—all of which marks are evidences of exposure above the water during the progress of the beds.

In the Connecticut valley, and to some extent also in New Jersey and Pennsylvania, the surface of the beds is sometimes marked with the footprints of animals, as Worms, Insects, Reptiles, and Birds; and Professor Hitchcock, who has made the tracks of the Connecticut valley his special study, has in the Amherst College Cabinet (at Amherst, Mass.) about 8000 tracks, averaging sixty-eight tracks for each species of animal. There are also numerous specimens in other collections in New England and elsewhere.

On the *Gulf border* there are no Triassic rocks, excepting such as may possibly be buried beneath later formations.

The formation beyond the Mississippi which is supposed to be Triassic consists of sandstones and marls of usually a brick-red color, and often contains gypsum. It outcrops at the base of the ridges of the Rocky Mountains, and covers wide areas. It is largely developed west of the summit in the Colorado valley, especially about the region of the Little Colorado.

(*a.*) *Atlantic border.*—The areas on the Atlantic border are as follow:—

1. The *Acadian*.—(1.) A region in Nova Scotia, forming the east side of the Bay of Fundy, and reaching eastward in this line, though with some interruptions by water, to the eastern borders of the Basin of Mines. (2.) Prince Edward's Island, which is covered throughout with it.

2. The *Connecticut River range*.—Extends along the Connecticut valley, from New Haven, on Long Island Sound, to the northern limits of Massachusetts,—a distance of one hundred and ten miles: the average width is twenty miles.

3. The *Southbury range*.—A small parallel region in Connecticut, more to the westward, in the towns of Southbury and Woodbury.

4. The *Palisade range*.—This is the longest continuous line,—being about three hundred and fifty miles in length. It extends from Rockland on the Hudson River, southwest, through New Jersey, Pennsylvania, and Virginia, east of the Blue Ridge, being thirty miles wide in some places in New Jersey, twelve on the Susquehanna, and six to eight on the Potomac. It crosses the Delaware between Trenton and Kintnerville, the Susquehanna at Bainbridge, and the Schuylkill twelve miles below Reading. The map (p. 323) gives the position of the beds in Pennsylvania, indicated by oblique lines.

5 and 6.—*Short ranges in Virginia*, parallel to the last, and more to the eastward. The easternmost, or *Richmond* range, commences on the Potomac, a few miles below Washington, and continues to Richmond and twenty-five or thirty miles beyond. The other lies twenty-five miles west of the Richmond range.

7. The *North Carolina range*.—It begins near Oxford, in Granville co., and follows nearly the line of the Richmond range (of Virginia), crossing Orange and Chatham cos. westward of Raleigh, passing Deep River, where it contains coal, and extending into South Carolina. It is one hundred and twenty miles long; on the Neuse it is twelve miles broad, between Raleigh and Chapel Hill eighteen miles; on the Cape Fear, not over eight miles.

As the several regions are isolated from one another, they naturally differ widely in the succession of beds and in the character of the rocks. They cannot, therefore, be brought into parallelism by reference to mineral characters.

In the Connecticut River region, in Massachusetts, according to Hitchcock, these beds consist, beginning below, of—

1. Thick-bedded sandstone through nearly half the thickness, in some parts a conglomerate.

2. Micaceous sandstone and shale, with fine-grained sandstone. This shale sometimes contains coal seams and fossil fishes.

3. A coarse gray conglomerate, the masses sometimes several feet through.

The material has come from the crystalline rocks adjoining,—the granite, gneiss, mica schist, talcose schist, etc. The thickness has not been satisfactorily ascertained: it cannot be less than 3000 feet, and may be more than double this.

At Southbury, Ct., and near Springfield, Mass., there is an impure gray or yellowish limestone fitted for making hydraulic lime.

In Virginia, they consist, as in New England, of the debris of the older crystalline rocks with which they are associated. Near Richmond, where the beds are 800 feet thick, there are 20 to 40 feet of bituminous coal in three or four seams alternating with shale, and in some places the coal shales are directly in contact with the subjacent granite and gneiss. The coal is of good quality, and resembles the bituminous coal of the Carboniferous era. It contains, according to

Hubbard (Amer. Jour. Sci. 1842, xlii. 371), 30 to 35 per cent. of volatile ingredients.

In North Carolina, the beds rest on the crystalline rocks, and have been derived from their wear. Emmons divides them into three groups, beginning below:—

1. The Lower red sandstone and its underlying conglomerate, estimated at 1500 to 2000 feet in thickness.

2. The Coal measures, including shales and drab-colored ripple-marked sandstones, in some places 1200 feet thick.

3. The Upper red or mottled sandstones and marls, separated at times from the bed below by a conglomerate.

There are five seams of coal at the Deep River Mines,—the first (or upper), and best, 6½ feet thick. The coal resembles that of Richmond, and is valuable for fuel. Emmons obtained 28 to 31 per cent. of volatile ingredients. The beds below the coal are of much less thickness in the Dan River coal region than in that of Deep River. Good argillaceous iron-ore abounds in the coal region of North Carolina, so that in almost every respect there is a close resemblance to the coal regions of older date. Both at Richmond and in North Carolina there are numerous coal plants in the beds, and many stems or trunks stand as they grew, penetrating the successive layers.

(*b.*) *Western Interior region.*—There is still some doubt as to the age of the beds of the Rocky Mountains referred to the Triassic period. Although very widely distributed, they seldom contain fossils; and the few found—an occasional piece of fossil wood and remains of Saurians—are not sufficient to settle the question. The beds of the eastern slope are known to underlie unquestionable Jurassic beds at the Black Hills in Dakota and the Red Buttes on the North Platte, and hence to occupy a position between the Jurassic and Permian; and to the latter they are unconformable. They therefore either belong to the Triassic or to an inferior part of the Jurassic formation. The rocks of the Upper Colorado, according to Newberry, lie between the Carboniferous and the Cretaceous, and the whole thickness is 2000 to 2500 feet. But it is not yet known whether all these beds are of the Triassic, or whether they cover both the Triassic and Jurassic periods. A bed of lignite with some coal plants was found by Dr. Newberry near the junction of the Cretaceous and the inferior red sandstone, containing a few fossil plants, which he observes may possibly be Jurassic, although it is not certain that they may not be Cretaceous.

II. Life.

There are two remarkable characteristics of the American Triassic period, according to the present state of discovery:—

1. The paucity of all distinctively marine life in the beds of the *Atlantic border.*

2. The absence of life of every kind, excepting some fossil wood and Reptiles, from the beds of the *Western Interior.*

There may have been on the Atlantic extensive coast-accumulations formed, containing numerous marine fossils, as in Europe; but none such are now exposed to view.

1. *Plants.*

The vegetation of the Triassic period includes no species of *Sigillaria*, *Stigmaria*, or *Lepidodendron*, characteristic genera of the Carboniferous era; but instead there are *Cycads*,* along with many new forms of Ferns, Equiseta, and Conifers. The figures beyond show this contrast between the flora of the Carboniferous and Triassic eras. Figures 626 and 627 represent the remains of leaves of some of the Cycads; figs. 652 and 652 *a*, one of the Conifers, a *Voltzia* related to the Cypress; and figs. 628, 629, and 630 are species of ferns. Trunks of Conifers occur occasionally in the sandstone. One found near Bristol, Ct., was fifteen or more feet long and one foot in diameter. No species of grass or moss have been met with. Many plants of remarkable forms found in Connecticut and Pennsylvania remain to be described.

The remains of plants are sufficient to show that the hills had

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* Gymnosperms (p. 166) are divided into (1) *Conifers*, comprising the Pine, Spruce, Hemlock, etc., (2) *Sigillarids*, the *Sigillariæ* of the Palæozoic; (3) *Cycads*, the plants above alluded to, of which the two most prominent groups are named *Cycas* and *Zamia*.

The Cycads, while related to the Conifers in structure and fructification, are totally different in habit. They have a simple trunk, with a tuft of large leaves or fronds at top, and thus much resemble a Tree-fern or young Palm. The fronds unroll in expanding, as in the Ferns, but their form is closely like that of many Palms. Yet, while resembling palm-leaves in shape, the leaflets have no tendency to split longitudinally, as in that tribe. Fig. 625 *a* represents a trunk of a short extinct species, a foot and a half in diameter, and 625 *b* one of the long fronds from the graceful cluster that crowns the top in a *Zamia*; both are very much reduced in size. The species of *Cycas* are sometimes 30 feet high, but those of *Zamia* are usually short, seldom exceeding 3 or 4 feet. The existing species are confined to warm climates, occurring in the West Indies, Mexico, and equatorial South America, in southern Africa and Madagascar; in southern Asia, Japan, and the East Indies; and in Australia.

Fig. 625.

their forest-vegetation of Conifers, Cycads, and Ferns, from which old trunks and leaves were occasionally swept into the estuaries, while the marshes were in some places accumulating vegetable debris and forming coal.

Characteristic Species.

Conifers.—The genus *Voltzia*, near the Cypress, has lax leaves, with the terminal often longer than the others; the fruit-branchlet consisted of broad

Figs. 626–630.

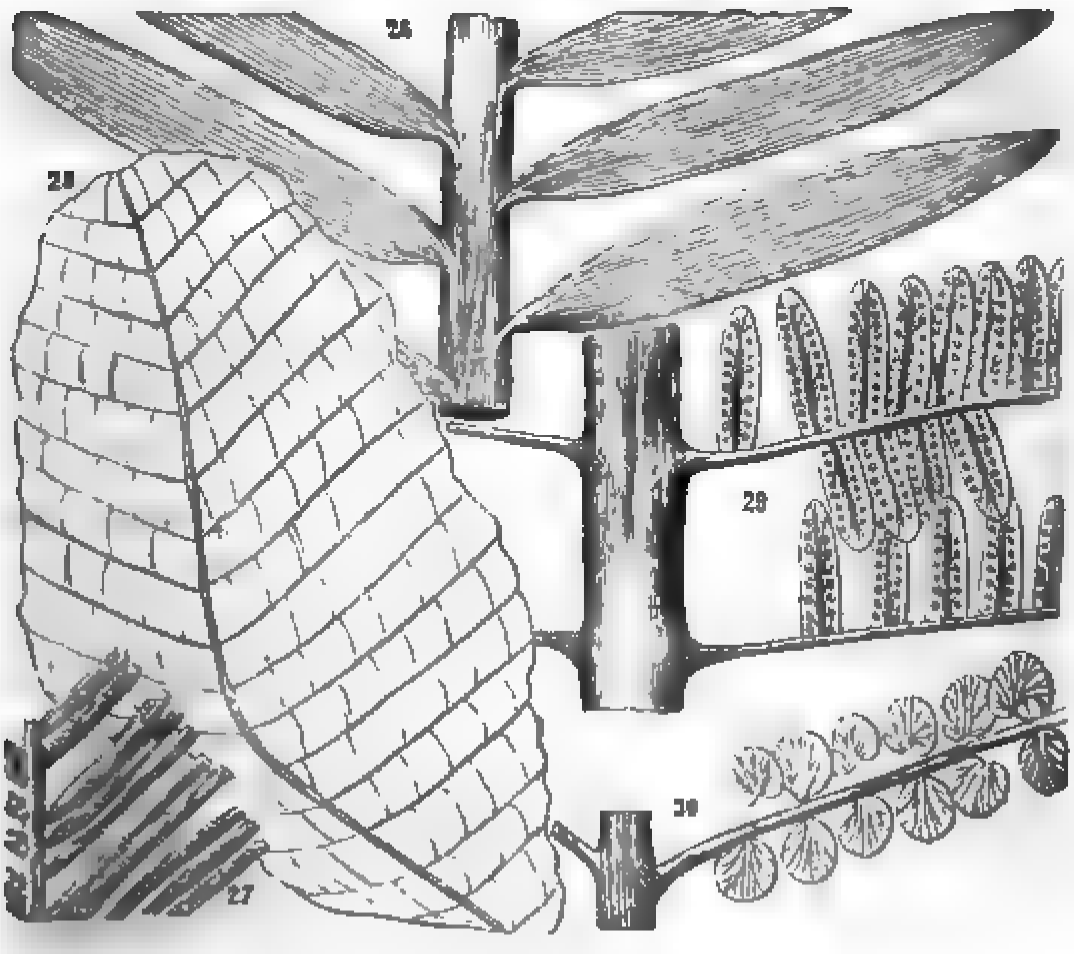

Fig. 626, Podozamites lanceolatus; 627, Pterophyllum graminioides; 628, Clathropteris rectiusculus; 629, Pecopteris Stuttgartensis; 630, Cyclopteris Linnæifolia.

and short leaves or scales. A species near *V. heterophylla* (fig. 652) has been found in the American rocks. One was found at the Little Falls of the Passaic, in New Jersey. Several *Fir-cones*, six inches long, have been found at Phœnixville, Pa., and a small one, from the Massachusetts beds, has been figured by Hitchcock.

Cycads.—The *Pterophyllum longifolium* Braun, from North Carolina and Pennsylvania, is characteristic of the Upper Trias in Europe; the species resembles fig. 653; *Pterophyllum graminioides*, fig. 627, is another North Caro-

lina species. Fig. 626 is the *Podozamites lanceolatus* Emmons, from the same locality.

Acrogens.—Fig. 628, *Clathropteris rectiusculus* Hitchcock, from East Hampton, Mass., near the middle of the Sandstone formation: in one specimen there were seventeen such fronds radiating from one stem. Fig. 629, *Pecopteris Stuttgartiensis*, a fern with the fruit, from the Richmond Coal beds, found also in the Trias of Europe. Fig. 630, *Cyclopteris Linnæifolia*, from Richmond. Other ferns are the *Acrostichites oblongus* and *Laccopteris falcatus* Emmons, both from North Carolina. *Equisetum columnare* occurs at Richmond, Va., and in Pennsylvania. One or two *Calamites* have been found in North Carolina.

The vegetation of the beds is decidedly Triassic in character. *Pecopteris Stuttgartensis* and *Pterophyllum longifolium* are Upper Triassic in Europe; *Laccopteris falcatus* closely resembles *L. germinans*, an Upper Triassic species; *Cyclopteris Linnæifolia* is near *C. pachyrachis*, also Upper Triassic; *Clathropteris* and *Voltzia* are Triassic or Jurassic. The prevalence of Cycadeæ is decidedly Triassic, and not Permian. *Calamites* and species of *Neuropteris* occur in the European Trias as well as in the Permian and Carboniferous.

2. *Animals.*

The Triassic rocks of the Atlantic border have afforded no traces of *Radiates*, and but few *Mollusks*. This singular fact is partly accounted for through another already stated,—that the beds are rarely marine, being in general either fresh-water or brackish-water deposits.

Articulates are represented by both Crustaceans and Insects. The Crustacean remains are, with a single exception, Ostracoids; and some of the species occur in great numbers: two of them are represented in figs. 631, 632. The only fossil Insect observed is the larve (or exuvia of the larve) of a *Neuropter* (fig. 632 B) related to the genus *Ephemera*, found by R. Field in the shale at Turner's Falls, on the Connecticut, and described by Hitchcock. It is about three-quarters of an inch long. This tribe of Insects appears to have been numerously represented in the Carboniferous Age (p. 358).*

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* *Neuropterous* Insects have four similar membranous reticulated wings; as the species of *Dragon-fly* or *Libellula, Termes, Phryganea, Ephemera.*

Orthopters have the outer pair of wings a little coriaceous; as the *Locust, Grasshopper, Cockroach.*

Coleopters have the outer wings wholly coriaceous and neatly meeting along the back; as the *Beetles.*

Hemipters have the outer wings coriaceous for about half their length only, as the *Squash-bug*, or uniformly thin, as the *Cicadæ;* the mouth is a sucking beak.

Lepidopters have large wings covered with minute scales; as the *Butterfly* and *Moth.*

But, although relics of Insects and of Crustaceans other than Ostracoids are rare, several species of these classes of Invertebrates, and also of Worms, are indicated by the tracks which they left on the material of the finer shales. Figs. 633–637 represent some of these footmarks. Those of Insects were probably made by larves which live in water, like those of many Neuropters. Nearly thirty species of Articulates have been named by Hitchcock from the tracks.

The *Vertebrates* thus far made known from their fossils and footprints outnumber all other kinds of animal life; and many were of remarkable size. They include not only *Fishes* and *Reptiles*, but also the first of *Birds* and *Mammals*.* Thus the sub-kingdom of

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Hymenopters have four membranous veined wings, the anterior the larger; as the *Bee, Wasp*.

Dipters have two membranous wings; as the *House-fly*.

These are the more common of the grand divisions of Insects. The *Hymenopters* are regarded as highest in rank. The *Lepidopters, Dipters*, and *Hemipters* have sucking mouths; in the other tribes mentioned there are jaws.

* With this first appearance of Mammals in the Geological history, a general view of the classification of this class is here presented.

Among Mammals there are three prominent groups:—

1. *Man*, who stands apart from the rest.

2. *True viviparous tribes* (or *non-marsupial*), including all ordinary Mammals, as the Monkey, Lion, Elephant, Ox, Whale, Bat, Mouse, etc.

3. *Semi-oviparous tribes* (mostly *marsupial*), in which birth takes place before the maturity of the young, as in oviparous animals, and including the Opossum, Kangaroo, Ornithorhynchus, etc. They are the lowest of Mammals. The *marsupial* species are so called because they have a pouch (in Latin *marsupium*) below, for carrying the immature young.

This third group is to some extent parallel in its series of species with the second, or non-marsupial; that is, there are Carnivores, Herbivores, Insectivores, Rodents, etc., in both groups,—so that the tribes of Mammals are represented under both types.

The non-marsupials, or higher Mammals, contain in themselves two distinct and parallel series, corresponding to two grand divisions:—

1. The *Megasthenes* (from μεγας, *great*, and σθενος, *strength*).—The superior type, based on a larger and more powerful type of structure or life-system, as the Monkey, Lion, and other *Carnivores*, Ox, Elephant, and other *Herbivores*, Whale and other *Mutilates*.

2. The *Microsthenes* (from μικρος, *small*, and σθενος).—The inferior type, based on a small and weak type of structure or life-system, as the Bat, Hedgehog, and other *Insectivores*, Mouse and other *Rodents*, Sloth and other *Brutes* or *Edentates*.

The parallelism between the two groups is complete. The Bats in the latter represent the Monkeys in the former, the orders having so close relations that they follow one another in Cuvier's classification; the *Insectivores* represent the

Vertebrates has from this earliest period of the Mesozoic all its grander subdivisions or classes represented.

The *Fishes* are all Ganoids (fig. 638), like the Palæozoic, but they

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Carnivores; the *Rodents* represent the *Herbivores*; and the *Edentates*, or Sloth tribe, the *Mutilates*. The Sloth tribe contains some large animals, but they have overgrown bodies, too bulky to be wielded well by the small life-system within. A system of structure fitted for active movement would have been thrown away upon them.

The true classification of Mammals is, hence, as follows:—

I. ARCHONTS—MAN (alone).

II. MEGASTHENES.

1. QUADRUMANA, or MONKEYS.—The members (or at least the posterior) furnished with hands,—that is, having a thumb opposable to the fingers for grasping; incisors two on each jaw; clavicles perfect; mammæ pectoral.

They include (1.) The *Strepsirrhines*, found in Madagascar, and diverging thence to Africa and the East Indies, having curved or twisted terminal nostrils, and the second digit of the hind limb a claw.

(2.) The *Platyrrhines*, peculiar to South America, having the nostrils subterminal and wide apart, the thumb of the fore hand not opposable, or wanting, and the tail in most prehensile.

(3.) The *Catarrhines*, confined to Africa and Asia, excepting one at Gibraltar, having the nostrils oblique and approximated below, and opening above and behind the muzzle; the thumb of the fore hand opposable.

These are the higher species, and among them the highest group is tail-less (the Orang and Chimpanzee).

2. CARNIVORES (Flesh-eaters, Beasts of prey).—Feet with claws (unguiculate) and the lower surface having the special sense of touch. The incisors three either side in each jaw (except in the Seals), and the canines one; canines longer than the other teeth. Molars trenchant or tuberculate, according as the food is more or less completely of flesh; clavicle rudimental or wanting.

(1.) *Digitigrades*.—Walking on the toes, without touching the heel to the ground, as the Lion, Cat, Dog, Weasel.

(2.) *Plantigrades*.—The palm of the hind feet touching the ground in walking, as the Bear, Raccoon, Badger.

(3.) *Pinnigrades*.—Moving by means of fin-like paddles, as the Seal, Walrus.

3. UNGULATES, or HERBIVORES (Plant-eaters).—Feet hoofed, unfit for grasping, and of low tactile sense; the limbs restricted in use to support and locomotion. Molars with broad summits, for grinding. No clavicles.

The number of toes is either even or odd,—that is, either two or four, or one, three, or five; and an important distinction is based upon this by Owen:—

(1.) ARTIODACTYLS, or *even-toed*.—Dorso-lumbar vertebræ nineteen. Horns, if any, in pairs. Include (1) the *Ruminants*, or animals

include species that have the tails only half-vertebrated, or not at all so. And thus it is that the progress of the Ages, as first observed by Agassiz, is marked in the tails of the Fishes.

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that chew the cud, which are all two-toed, as the Cow, Sheep, Antelope, Anoplotherium, Camel. (2) The *Omnivores*, as the Hog.

(2.) PERISSODACTYLS, or *odd-toed*. Dorso-lumbar vertebræ more than nineteen. Horns, when any, never in pairs. Include (1) the *Solidungulates* (solid-hoofed), or one-toed, as the Horse, Ass, Anchitherium, Hipparion [Macrauchenia?]. (2) *Multungulates*, having three or five toes, as the Tapir (hind feet three-toed, front four-toed), Rhinoceros (three-toed), Palæotherium (three-toed), Lophiodon, etc. (3) *Proboscidia*, as the Elephant, Mastodon, having five toes, and a proboscis, with tusks from one or both jaws.

4. MUTILATES.—The limbs short and paddle-like, for swimming. (1) *Cetaceans*, as the Whales. (2) *Sirenia*, as the Lamantin or Manatus, and the Dugong or Halicore.

III. MICROSTHENES.

1. CHIROPTERS, or BATS (analogues of the Quadrumana).—Having wing-like expansions of the fore limbs. Mammæ pectoral. Hibernate. Subdivisions—(1) *Insectivores*, or Insect-eaters, and (2) *Frugivores*, or Fruit-eaters.
2. INSECTIVORES (Insect-eaters, analogues of the Carnivores).—The molar teeth studded with conical points and associated with incisors and canines. Legs short. Slow in movement, as the Mole, Shrew, Hedgehog.
3. RODENTS, or GNAWERS (Fruit and Root eaters, analogues of the Herbivores).—Molars with flat, grinding summits; two long incurved incisors in each jaw, separated by a wide space from the molars: as the Mouse, Squirrel, Beaver, Porcupine, Capybara. Many hibernate.
4. BRUTES, or EDENTATES (analogues of the Mutilates).—The incisors and canines, with a rare exception, wanting, and some species wholly without teeth. The sacrum made of two united vertebræ, as in Reptiles. Twenty-three ribs,—an unusual number, also a Reptilian feature. The teeth without enamel, and none ever replaced by a new set. Legs with claws, but motions all slow. Include—

   (1.) The *Dasypus* or *Armadillo* group, covered with scales or a carapax,—*e.g.*, Armadillo or Dasypus, Chlamydophorus, Glyptodon, Chlamydotherium, Pachytherium.

   (2.) The *Bradipus* or *Sloth tribe*, without a carapax or coat of mail, and mostly covered with hair; furnished with molars, as the Sloth, Megatherium, Megalonyx, Mylodon, Scelidotherium.

   (3.) The *Myrmecophagus* or *Ant-eater tribe*, as the Myrmecophagus (Ant-eater), Orycteropus.

IV. SEMI-OVIPARANS, or OÖTICOIDS.

1. MARSUPIALS (from *marsupium*, a *pouch*).—Young prematurely born, and carried while still in the embryonic state in a pouch over the belly,

The *Reptiles* must have been very diversified in form and size, but, although fragments of the skeletons of several species have been found, a much larger number are known only from their footprints. The fossils have been discovered in Prince Edward's Island (Nova Scotia), Pennsylvania, and North Carolina. One of the most interesting localities is at Phœnixville, Pa., where there is literally "a bone-bed," as recently described by Wheatley. Some of the teeth of the Reptiles are shown in figs. 645–648. The animals belonged, apparently, to the tribe of Lacertians (Lizard tribe), and to that of Labyrinthodonts. Fig. 645, from the tooth of a Reptile found in Prince Edward's Island (*Bathygnathus borealis* Leidy) is reduced one-half.

There may also have been Flying Reptiles, *Pterodactyls* or species of some other unknown genus of Pterosaurs; for a fossil found by Wheatley at Phœnixville, Pa., much resembles, according to Leidy, the wing-finger of such a Reptile: it consists of two slender, hollow bones joined by an articulation. None of the footprints correspond in form to the foot of a Pterodactyl; but it is doubtful whether any tracks of a flying species could reasonably be looked for.

The Reptilian footprints (figs. 639–644) vary from a length of one-fourth of an inch to twenty inches, and many of them

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with the mouth attached to the nipples; having two bones, called marsupial bones, attached to the anterior margin of the pelvis; as the Opossum (Didelphys), Kangaroo (Macropus), etc.

2. MONOTREMES.—Without teeth; no external ears; no pouch, but still having marsupial bones:—*e.g.* (1) the Ornithorhynchus, having a covering of hair and a duck bill; (2) the Echidnus, having a covering of spines and hair, with the habit of the Porcupine.

This order includes several groups, which are approximately parallel with those of the Non-marsupials.

(1.) *Marsupial Monkeys*.—Ex., the genus Phalangista (Phalangers), Phascolarctos.

(2.) *Marsupial Carnivores*.—Ex.. Dasyurus (Bear-Opossum), Thylacinus (Dog-faced Opossum), Thylacoleo.

(3.) *Marsupial Herbivores* (approximately).—Ex., Hypsiprymnus, Macropus (Kangaroo), Nototherium; and of the *Pachyderm* tribe, the great Diprotodon.

(4.) *Marsupial Insectivores*.—Ex., Perameles (Bandicoots), Chæropus, Myrmecobius, Didelphys (Opossum).

(5.) *Marsupial Rodents*.—Ex., Phascolomys (Wombat).

(6.) *Monotreme Edentates*.—Ex., Echidnus, Ornithorhynchus.

The living species are confined to Australia, Tasmania, and the continent of America, one species—the Opossum—occurring in North America.

appear to have been made by Batrachians or Labyrinthodonts. While the smallest tracks indicate species of diminutive size as compared with a modern frog, the largest must have been of enormous dimensions. Professor Hitchcock calls the most gigantic of these species *Otozoum Moodii.* The animal had a stride of three feet, and appears to have walked like a biped, only occasionally bringing his fore feet to the ground, as impressions of the latter are not often distinct. Fig. 644 is the fore foot of this species, much reduced (twenty inches being its full length), and 644 *a* the hind foot: their relative sizes are here retained. One of the specimens of this species in the Amherst Cabinet is a slab thirty feet long, containing eleven tracks.

In some species the impressions of the hind feet have but three toes and resemble the tracks of birds. This is seen in fig. 641 *a* (*Anomœpus scambus* Hk.).

The print of the fore foot of the same animal is four-toed, as shown in fig. 641. These figures are one-sixth the natural size. It is remarkable that the toes of the hind feet have two, three, and four phalanges successively, like the toes of birds,—a peculiarity now unknown among Reptiles, but which characterized afterwards the Iguanodon, the giant Reptile of the Wealden.

Professor Hitchcock has described over fifty species of Reptiles from the tracks found in the sandstone of the Connecticut valley.

The evidence with regard to the existence of *Birds* at this period has been shaken somewhat by the discovery of the three-toed reptile-tracks; and it is not impossible, as was early suspected, that all the supposed bird-tracks may turn out to be Reptilian. Still, this does not appear probable.

The largest of the bird-tracks was of gigantic size, like the largest of those of the Reptiles. Fig. 649 shows the form. It was nearly two feet long; and from its depth and the great length of stride it is evident that the animal was tall and heavy,—probably fourteen feet high, exceeding the Ostrich of our day, and even the huge Moa of New Zealand. Smaller species were common, and many of them have been described. Fig. 649 A (from Hitchcock) represents a large slab, with its lines of tracks, showing that a number of birds (*a*, *b*, *c*) and batrachians (*d*) passed along over the muddy surface during the same day, or before the tides or freshets made new depositions of detritus: the tracks *a*, *a*, are enlarged views of *b*, and still are only one-tenth of the natural size. The birds of the period appear to have been either long-legged waders, or species of the Ostrich type. None were web-footed.

The number of species of birds named by Hitchcock from the footprints of the Connecticut valley is thirty-one.

Fossil bones have been obtained from these beds at Windsor, Ct. They are hollow, and may have belonged to birds; but Dr. Wyman states that it is also possible that they were the bones of Flying Reptiles.

The only *Mammal* thus far made known was discovered by Professor Emmons in North Carolina. The specimen is a jaw-bone (fig. 650), and it belonged, according to Professor Owen, to an Insectivorous (Insect-eating) Marsupial near the modern genus *Myrmecobius* of Australia. The species has been named by its discoverer *Dromatherium sylvestre.*

It is altogether probable that Mammals of similar kind were associated with the Birds and Reptiles in the Connecticut valley. To give some idea of the general form of the earliest of Mammals, a drawing of the *Myrmecobius* is given in fig. 663 B. The genus is confined to Australia.

Characteristic Species.

1. **Mollusks**.—*Conchifers.*—*Myacites Pennsylvanicus* Conrad, from the Black slate of Phœnixville, Pa. Two other species, referred by Wheatley with a query to Pholadomya and Unio or Potamomya, occur at the same locality.—An imperfect shell from near Mount Tom, Mass., is referred by E. Hitchcock, Jr., to the *Rudistes.*—The *Posidoniæ*, formerly supposed to be Molluscan, are now regarded as Crustaceans of the genus *Estheria.*

2. **Articulates**.—(*a.*) *Crustaceans.*—Ostracoids: Fig. 631, *Estheria ovata* (Posidonia minuta), from Richmond, Va., and Phœnixville, Pa., resembles the *P. minuta* of the European Trias; fig. 632, *E. ovalis* Emmons, from North Carolina; fig. 632 A, *E. parva* Lea, Phœnixville, Pa. (= E. ovalis ?). Two species of

Figs. 631–632 B.

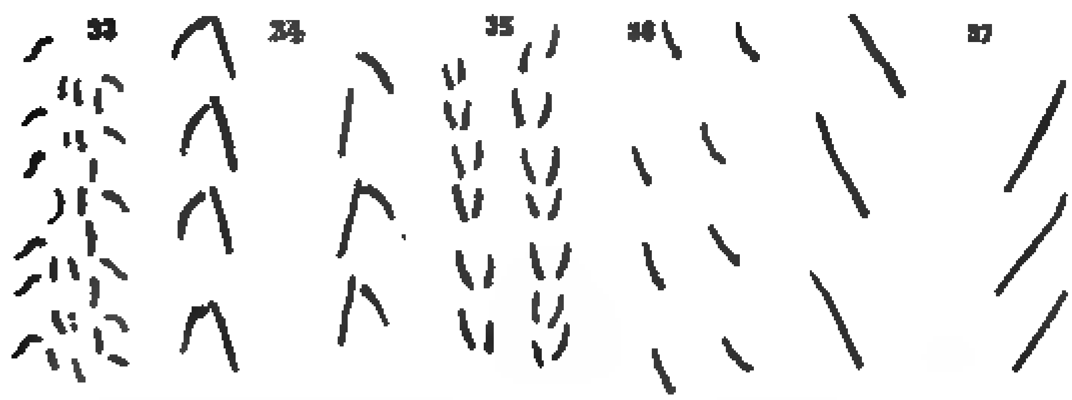
Fig. 631, Estheria ovata; 632, E. ovalis; 632 A, E. parva; 632 B, Palephemera mediæva ($\times \frac{3}{2}$).

Cypris, one smooth and the other granulate, occur at Phœnixville and Gwynned, Pa. Figs. 636, 637 represent tracks referred by Hitchcock to Macrouran Crustaceans.

(*b.*) *Insects.*—Fig. 632 B, exuvia of a Neuropterous larve, related to *Ephemera*, according to J. L. Le Conte. The appendages along the sides are probably

branchiæ attached to the abdomen. Tracks of different insects are shown in figs. 633–635, from Hitchcock. On comparing especially figs. 633, 634 with

Figs. 633–637.



Figs. 633–635, Tracks of Insects; 636, 637, Tracks of Crustaceans?

the footprints of some living Insects, Dr. Deane found a close resemblance between them.

3. **Vertebrates.**—(*a*.) *Fishes*.—Fig. 638, *Catopterus gracilis* Redfield (reduced one-half), from Middlefield, Ct., and also from North Carolina and Phœnixville, Pa.; 638 *a*, scale of same, natural size. There are also other species

Fig. 638.

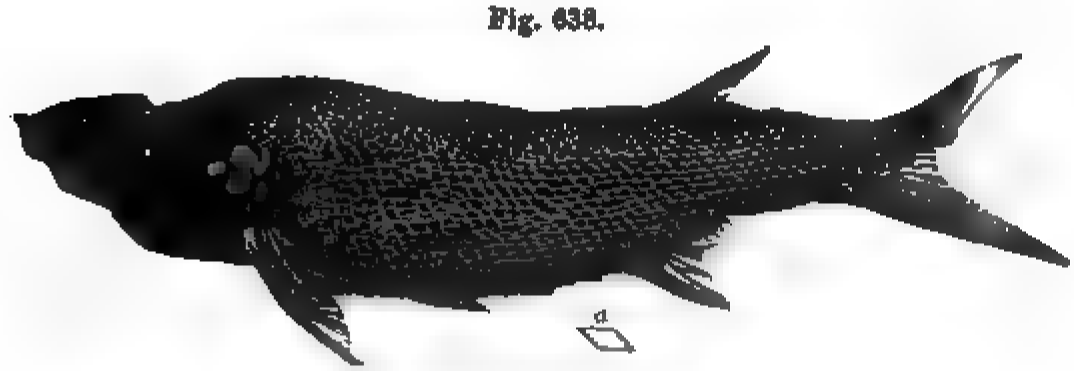


Fig. 638, Ganoid, Catopterus gracilis (× ½); *a*, Scale of same, natural size.

of *Catopterus*; also species of *Ischypterus*, and of *Turseodus* Leidy (related to Belonostomus or Eugnathus). In the last the tail is not at all vertebrated or heterocercal. *Radiolepis speciosus* Emmons is another Ganoid, from North Carolina and Pennsylvania.

The best localities of fossil fishes are Sunderland, Mass.; Middlefield Falls and Southbury, Ct.: Richmond Coal beds, Va., Phœnixville, Pa.

(*b*.) *Reptiles*.—(1.) *Amphibians*.—Fig. 643, *Anisopus gracilis* Hk., reduced one-third. Fig. 642, *Anisopus Deweyanus* Hk., half natural size. Fig. 639, *Macropterna divaricans* Hk. (reduced to one-sixth), may also be Batrachian. Fig. 644, *Otozoum Moodii* Hk., is possibly allied distantly to the Labyrinthodonts, although differing much from the known Labyrinthodont tracks. Portions of the skeleton of Labyrinthodont Amphibians have been detected by Leidy among the

fossils of Gwynned, Pa., twenty miles north of Philadelphia, and also among those found at Phœnixville; and Emmons has figured a portion of the head of a fine species from North Carolina.

Figs. 639–644.

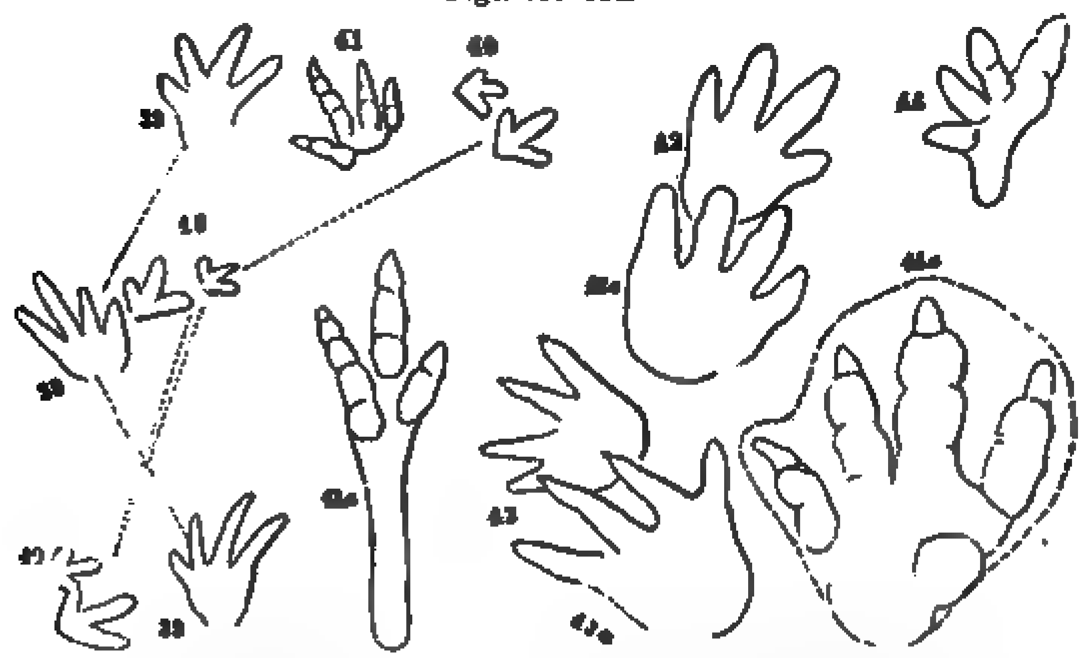


Fig. 639, Macropterna divaricans (× 1/6); 640, Apatichnus bellus (× 1/3); 641, Anomœpus scambus, fore foot (× 1/6); 641 *a*, hind foot of same, 642, Anisopus Deweyanus, fore foot (× 1/3); 642 *a*, hind foot of same: 643, A. gracilis, fore foot (× 3/5); 643 *a*, hind foot of same, 644, Otozoum Moodii, fore foot; 644 *a*, hind foot of same (both × 1/18).

(*b.*) *Lacertians.*—Fig. 647 is a tooth, natural size, of the *Clepsysaurus Pennsylvanicus* Lea. It has a sharp denticulate edge. Occurs in Division 1 in North Carolina, and also near Phœnixville, Pa. *Centemodon sulcatus* Lea is the name of a related Reptile from Phœnixville. Fig. 648 is a striated tooth of *Rutiodon Carolinensis* Emmons. Fig. 646, tooth referred to a *Palæosaur*,—one of the Thecodont Lacertians,—a short and broad flattened tooth. Fig. 645, *Bathygnathus borealis* Leidy, from Nova Scotia (reduced one-half). Coprolites are abundant in the shales of Phœnixville. Fig 641, *a*, *Anomœpus scambus* Hk., is probably the track of a Lacertian, but its relations are very doubtful.

A general review of the Pennsylvania species, with notes on others, is given by Wheatley in Am. Jour. Sci. [2] xxxii. 41.

Figs. 645–648.

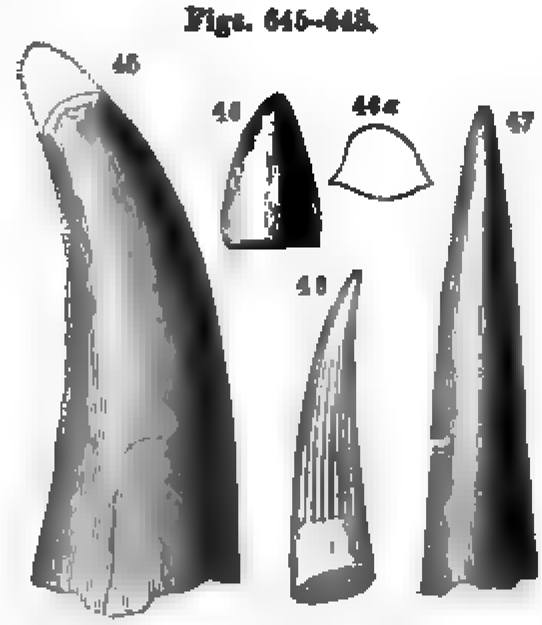
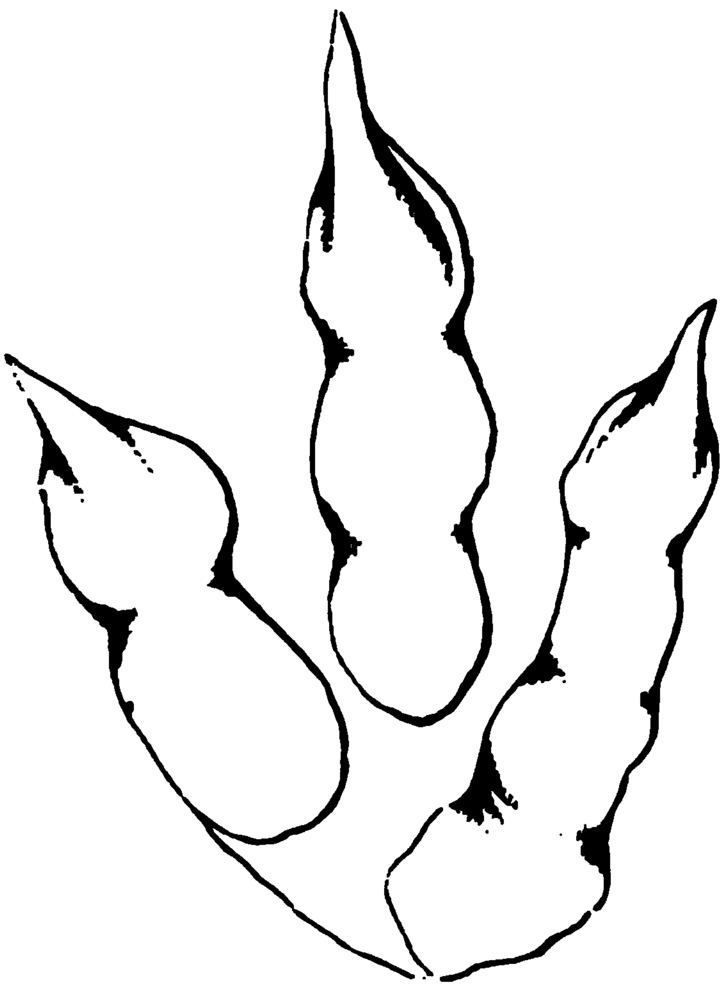


Fig. 645, Bathygnathus borealis (× 1/2); 646, Palæosaurus Carolinensis; 646 *a*, section of same; 647, Clepsysaurus Pennsylvanicus; 648, Rutiodon Carolinensis.

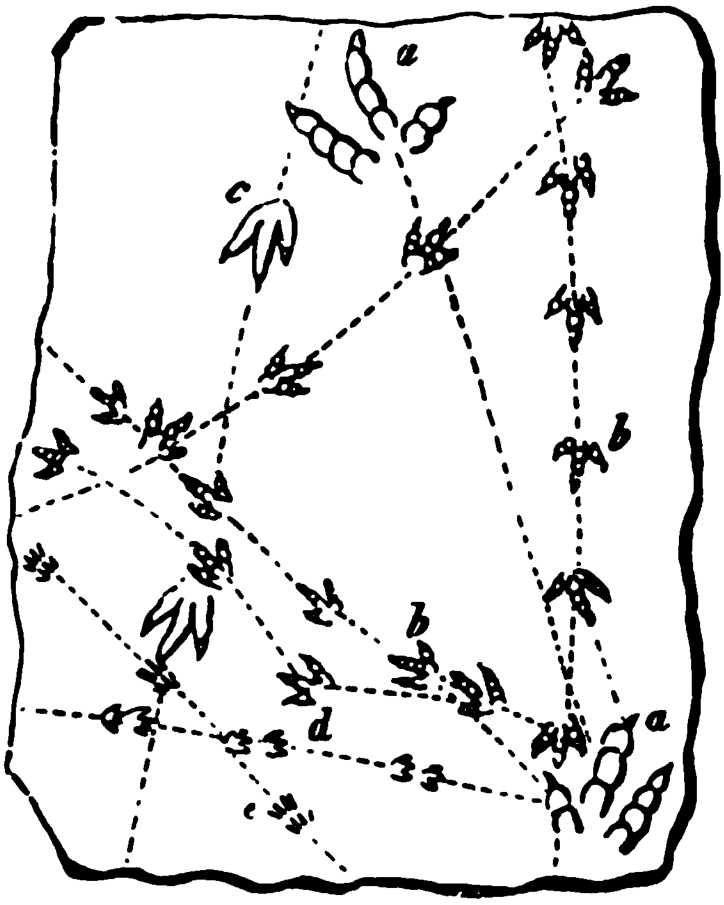
(*c.*) *Birds.*—Fig. 649, *Brontozoum giganteum* Hk., reduced to one-sixth natural size. Fig. 649 A represents part of a slab of sandstone figured by Hitch-

Fig. 649.



Brontozoum giganteum ($\times \frac{1}{6}$).

Fig. 649 A.

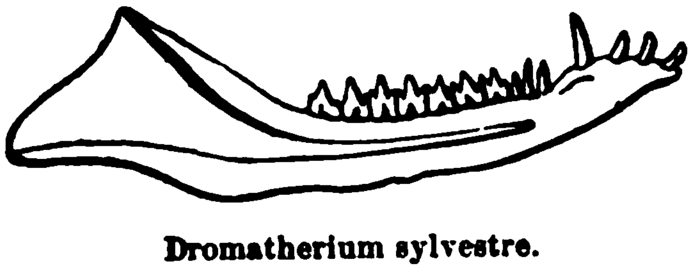


Slab of sandstone, with tracks of Birds and Reptiles ($\times \frac{1}{30}$).

cock, one-thirtieth natural size lineally: *a, b, c,* are three kinds of bird-like tracks; *a* and *c* are of the genus *Brontozoum* Hk.; *a, a,* same as *b*, but drawn larger to show the articulations of the toes. Figs. *d, e,* are two kinds of Reptilian tracks of the genus *Anisopus* Hk., *d Anisopus Deweyanus* Hk. Natural length of *a*, 4 inches; of *b*, 8 to 9 inches; of *c*, $3\frac{3}{4}$ inches; of *d* and *e*, 1 to $1\frac{1}{2}$ inches. The best localities of tracks of birds and other animals are at Greenfield and Turner's Falls, Mass.; Portland, Conn.

(*d.*) *Mammals.*—Fig. 650, *Dromatherium sylvestre* Emmons, from North Carolina. Owen says of the species that "this Triassic or Liassic Mammal would appear

Fig. 650.



Dromatherium sylvestre.

to find its nearest living analogue in *Myrmecobius;* for each ramus of the lower jaw contained ten small molars in a continuous series, one canine and three conical incisors,—the latter being divided by short intervals."

III. Disturbances—Igneous action—Trap rocks.

Trap ridges and dikes accompany this formation on the Atlantic border. The rocks constituting them are of igneous origin, and were ejected in a melted state through fissures in the earth's crust. It is remarkable that these fractures should have taken place in great numbers just where the Triassic beds exist, and only sparingly east or west of them. The igneous and aqueous rocks are so associated that they necessarily come into the same history.

The era of these ejections is supposed to have begun near the middle of the Sandstone period. But it may have continued into, or been mostly confined to, the period next following the deposition of the beds. Professor Hitchcock reports that near Mount Tom tufaceous layers made of fragments of scoria intervene between the sandstone beds near the middle of the series, proving that the ejection took place before the following beds had been deposited; but after an examination of the region the author regards it as more probable that the appearance of scoria is owing to an escape of steam laterally from between the opened strata during the ejection of the trap of the adjoining mountain. Mount Tom and Mount Holyoke, of Massachusetts, are examples of these trap ridges; also East and West Rock, near New Haven, and the Hanging Hills, near Meriden, in Connecticut; the Palisades along the Hudson, in New York; Bergen Hill and other elevations in New Jersey.

In Nova Scotia there is a long range of trap skirting the whole red sandstone region and facing directly the Bay of Fundy; Cape Blomidon, noted for its zeolitic minerals, lies at its northern extremity, on the Bay of Mines.

In Connecticut the ridges and dikes are exceedingly numerous, showing a vast extent of igneous action.

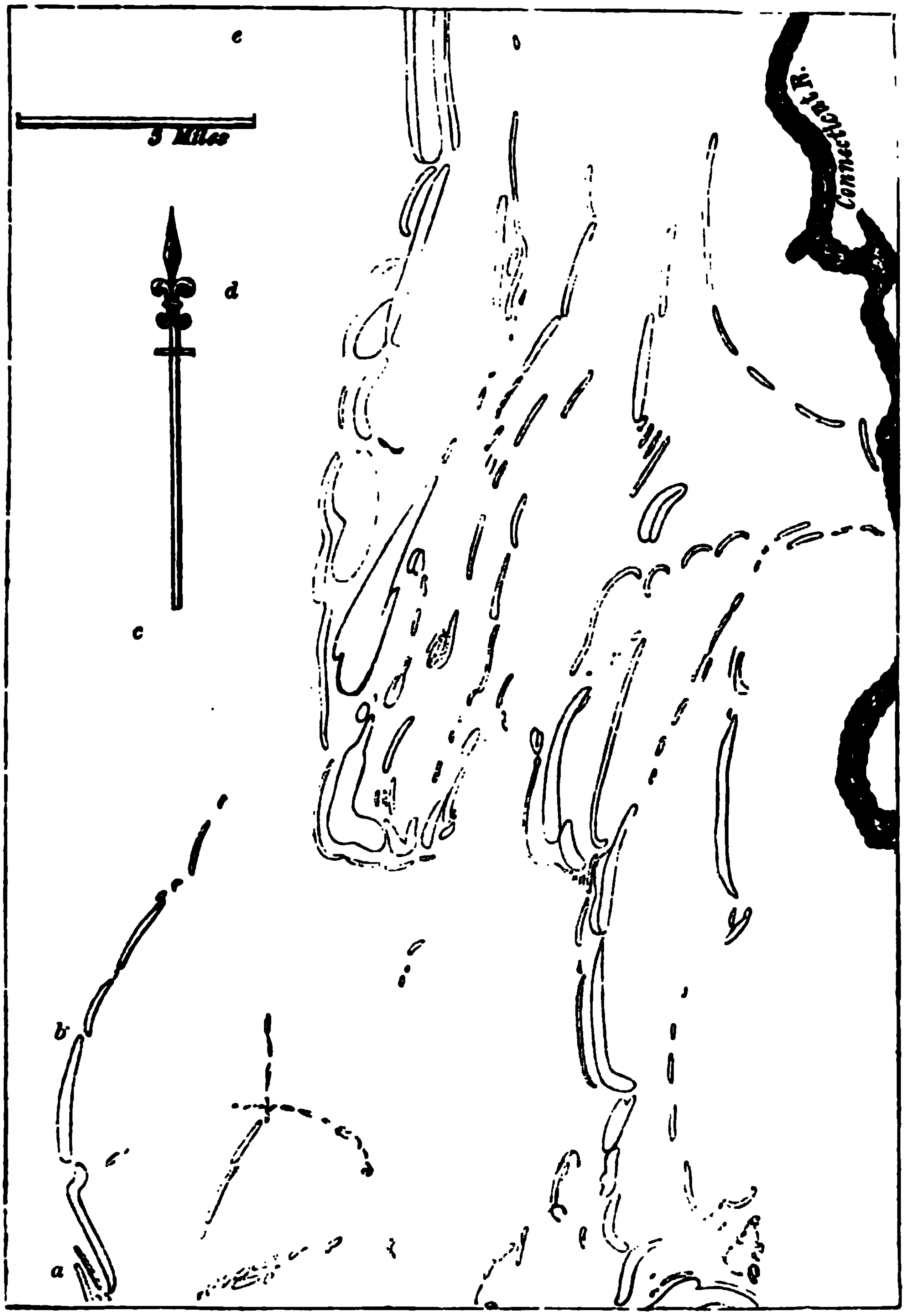
The following map (fig. 651), from a more complete one of the State by Percival, will give some idea of their number and position. They commence near Long Island Sound, at New Haven, just south of the southern portion of the map, where they form some bold eminences, and extend through the State, and still farther north, nearly to the north boundary of the State of Massachusetts. Mounts Holyoke and Tom are in the system. The general course is parallel with that of the Green Mountains.

Although the greater part of the dikes are confined to the sandstone regions, there are some lines outside, intersecting the crystalline rocks and following the same direction. These also may be parts of the system, for those in the sandstone actually intersect

these crystalline rocks, underneath the sandstone. Even the little Southbury Triassic region has its trap, and it has the same direction as in the Connecticut valley.

The trap usually forms hills with a bold columnar front and

Fig. 651.



Map of part of the region in central Connecticut between New Haven on the south and Windsor on the north, showing the trap dikes which intersect the region; *a*, *b*, *c*, *d*, *e*, course of western boundary of Triassic, beyond which the rocks are metamorphic.

sloping back. In many cases it occurs simply as a narrow dike. It has come up through fissures in the sandstone, and, as it escaped, it often thickened up into high elevations; yet nowhere does it seem to have flowed far over the surface. In many cases it has made its way out by opening the layers of sandstone; and, owing to the direction of the dike or fissure, and that which this lateral escape was calculated to produce, the ridge of trap has often assumed a curved form, as apparent in the map.

The proofs that the trap was actually melted are abundant. For the sandstone rocks have in many places been baked to a hard grit by the heat, and at times so blown up by steam as to look scoriaceous. In some places the uplift has opened spaces between the layers, where steam has escaped and changed the clayey sandstone into a very hard rock looking like the trap itself. Occasionally crystalline minerals, as epidote and tourmaline, are among the results of the baking. The evidences of heat, moreover, diminish as we recede from the ridges; and there is no doubt that the sandstone has been extensively worn away by waters where it had not been rendered durable by the heat.

In all the several regions along the Atlantic border the strata are in most parts much tilted. In North Carolina there is in general a dip of 10° to 22° to the southwest (Emmons); in Virginia, Maryland, Pennsylvania, and New Jersey, the dip is to the northwest or north-northwest (Rogers); in Connecticut and Massachusetts, to the east or southeast (Hitchcock). But there are many variations at short intervals. In the Portland quarries there are joints on a grand scale, having two transverse courses, nearly north-and-south and east-and-west.

Some of the dikes of trap and fissures in the sandstone in Connecticut and New Jersey contain copper-ore (copper-glance, erubescite and malachite), and there is little doubt that the copper veins, and the barytes which is often the gangue of the vein, originated in the same period of eruption. The red color of the sandstone—a consequence of oxydation of magnetic-iron grains present in it—appears to have had its origin in the same cause.

This history of the Triassic of the Atlantic border and its trap dikes appears to be a repetition of what took place long before, during both the Huronian and Potsdam periods, in the Lake Superior region, where a similar subsidence (10,000 feet in the former, and 3000 or 4000 in the latter), and similar igneous eruptions, accompanied the formation of the beds.

2. FOREIGN TRIASSIC.

The region over which the Triassic rocks outcrop in England stretches across the island from south-southwest, along by the British Channel, to the north-northeast, and also from the centre of this band, along a northwestward course, to Liverpool, and thence north up the west coast, thus dividing England into four parts,—a southwestern (the peninsula of Cornwall and Devon), a southeastern, a western (Wales), and a northern,—indicating the existence of an archipelago of British Isles in the Triassic period.

In Europe the Trias is found largely developed in regions east and west of the Rhine, from northern Switzerland northward; on the east side, through Wurtemberg, Odenwald, Thuringerwald, and by Giessen; and on the west side, along the Vosges, by Strasbourg and Metz, to Aix. The beds occur also in other parts of central Europe, in the eastern Alps, Poland, Russia, Spain, etc.

I. Rocks: kinds and distribution.

The subdivisions recognized in France and Germany are *three* in number; whence the name, from the Latin *tria, three*. The beds are denominated in these countries and England as follow, beginning with the lowest:—

I. *England.*	II. *France.*	III. *Germany.*
Saliferous beds, or New Red Sandstone, 1200 to 1700 feet.	1. Grès bigarré.	1. Bunter Sandstein, 1200 to 1600 ft.
	2. Calcaire Coquillier.	2. Muschelkalk, 1000 to 1200 feet.
	3. Marnes irisées.	3. Keuper.

In English works the names of the European beds are translated as follow: 1. Variegated sandstone; 2. Shell limestone; 3. Red marls or Keuper;—yet they are often written without translation. The names indicate the kinds of rocks. In England they are sandstone and mottled clays (marls), mostly red; in Europe, near the Rhine, a thick fossiliferous impure limestone lies between a sandstone above and marls below.

This formation contains the principal salt beds of Europe, and hence it is often called the *Saliferous system*. The salt in Germany is connected with the middle group, as in Wurtemberg, where there are noted salt-works. In Vic and Dieuze, France, they are in the upper; and a thickness of 180 feet of rock-salt occurs in the course of 650 feet of rock. The salt layers alternate with clay and gypsum or anhydrite. In England the upper part affords the salt; and at Northwich, in Cheshire, two beds of salt, nearly pure, are 90 to 100 feet thick.

II. Life.

The species of fossils in the European Triassic are far more varied and numerous than in the American. The beds have

afforded teeth of one species of mammal, but fail of relics of birds. Near Wurtemberg, Germany, there is a bone-bed, full of bones of fishes and reptiles, in the upper part of the "Keuper," and another in the "Muschelkalk;" and in England a similar bone-bed exists near the top of the series.

1. *Plants.*

Equiseta, Ferns, Cypress evergreens, and Cycads are the prevailing forms. No true Grass, Moss, Palm, or Angiosperm has yet been found in beds of this period.

Characteristic Species.

Fig. 652 is a branch of the *Voltzia heterophylla*, of the Cypress group. Fig. 653, *Pterophyllum Jægeri*, from Stuttgart. There are also species of *Equisetum*, *Calamites*, etc. Some names of European plants are given on p. 420. *Ætho-*

Figs. 652, 653.

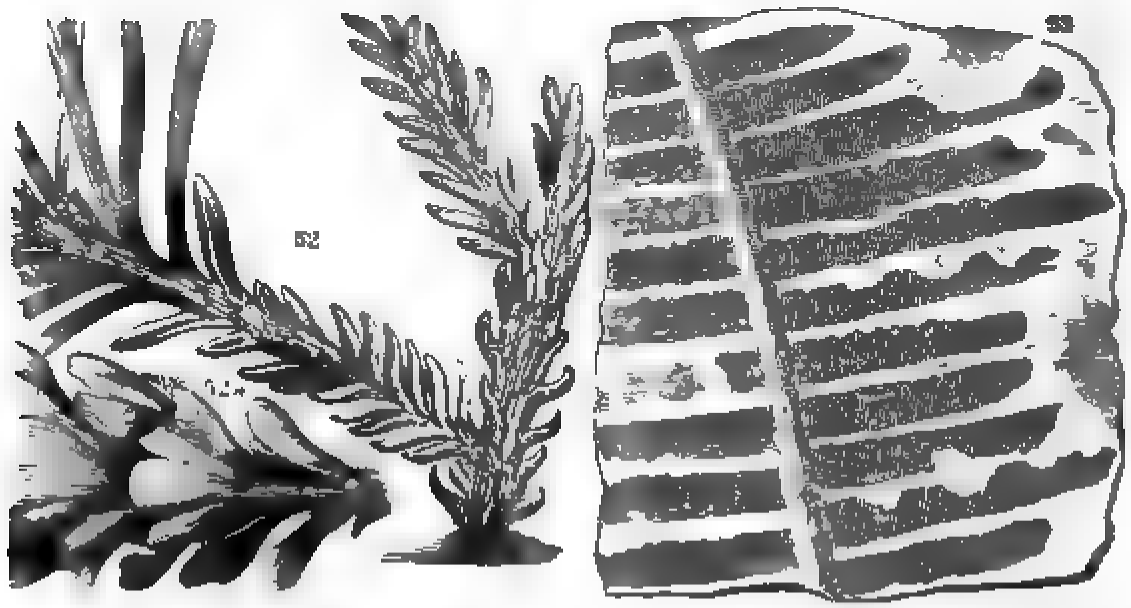


Fig. 652, Voltzia heterophylla; 652 *a*, one of its fruit-bearing branches; 653, Pterophyllum Jægeri.

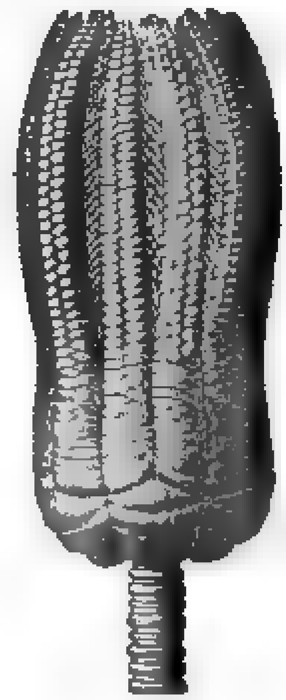
phyllum speciosum, *Æ. stipulare*, *Echinostachys oblonga*, and *E. cylindrica* are names of species of grass-like plants referred to the Typhaceæ or "Cat-tail" family.

2. *Animals.*

Radiates, though not abundant, are represented by Crinoids, Star-fishes, and a few Corals. Of the first there is the beautiful

Lily Encrinite, *Encrinus liliiformis*. Mollusks are numerous, and among them are the first of the *Ammonites*. The Articulates are confined to Crustaceans and Worms.

Fig. 654.



Encrinus liliiformis.

Among Vertebrates, the Fishes are all *Ganoids* or *Selachians*.

The Reptiles include the gigantic *Labyrinthodon*, a scale-covered animal of a Batrachian form, the skull of which was three or four feet long, and the teeth three inches,—magnitude enough for the *Otozoum* of the Connecticut valley. The tracks referred to a genus named *Chirotherium* (because of a resemblance in form to the human hand) are supposed to be those of a *Labyrinthodon*. The rocks also contain remains of Swimming Saurians (Enaliosaurs) and Lacertian Reptiles. Remains of 12 species of Labyrinthodonts, 16 of Enaliosaurs, and 12 to 15 of other Saurians, have been found.

The species of Mammal, *Microlestes antiquus* (fig. 663 A), is closely related to that of North Carolina.

Characteristic Species.

1. **Radiates.**—Fig. 654, *Encrinus liliiformis*, from the European "Muschelkalk." The limestone in some places is mostly made of Crinoidal remains. *Aspidura loricata* is a Star-fish related to the Ophiuræ.

2. **Mollusks.**—(*a.*) *Brachiopods.*—*Terebratula vulgaris*, *Spirifer uncinatus*, etc. (*b.*) *Conchifers.*—Fig. 655, *Avicula? socialis*. Fig. 657, *Myophoria lineata*, of the Trigonia family; also species of *Gervillia*, *Avicula*, *Pecten*, etc. (*c.*) *Cephalopods.*

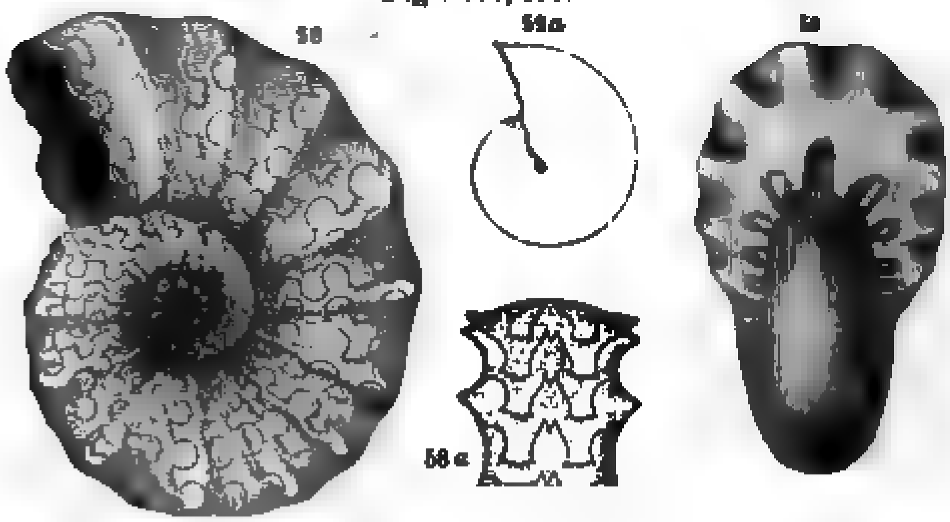
Figs. 655–657.

Conchifers.—Fig. 655, Avicula? socialis; 656, Estheria minuta; 657, Myophoria lineata.

—Fig. 658, *Ceratites nodosus*, related to the Ammonites, but differing in the greater simplicity of the lobes of the septa. Fig. 659, *Ammonites tornatus*, from

St. Cassian; two species of *Orthoceras* have been described from the same place.

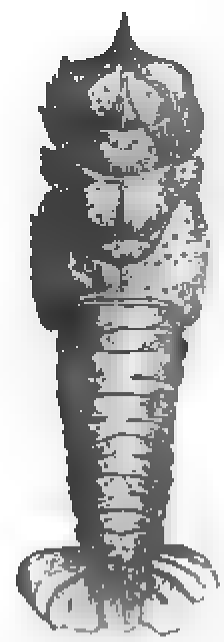
Figs. 658, 659.



CEPHALOPODS.—Fig. 658, Ceratites nodosus; 658 *a*, dorsal view of portion of same, showing the dorsal lobes of the septa; 659, Ammonites tornatus; 659 *a*, side-view of same (×½).

3. **Articulates.**—(*a.*) *Crustaceans.*—Ostracoids: Fig. 656, *Estheria* (*Posidonia*) *minuta.*—Macrourans: Fig. 660, *Pemphix Sueurii*, a species near the Crawfish (genus Astacus).—(*b.*) *Insects.*—Species of *Curculionites*, *Glaphyroptera*, etc.

Fig. 660.



Pemphix Sueurii.

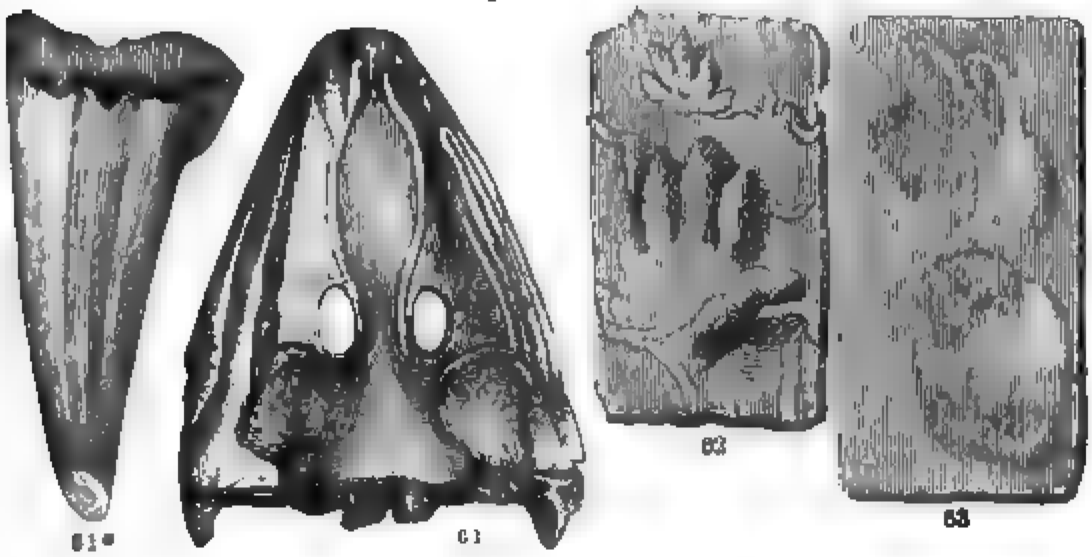
4. **Vertebrates.**—(*a.*) *Fishes.*—Among Hybodont Selachians, fig. 469, *Hybodus plicatilis* Ag., fig. 468, *H. minor* Ag. Among Cestracionts, species of *Acrodus*, *Ceratodus*, etc. Ganoids especially of the genera *Saurichthys*, *Gyrolepis*, *Amblypterus*, and *Palæoniscus*, the last of the heterocercal species; and of the Pycnodont division, *Pycnodus gigas*, etc.

(*b.*) *Reptiles.*—(1.) *Amphibians* of the Labyrinthodont tribe. Fig. 661, *Labyrinthodon* (*Mastodonsaurus*) *giganteus*, reduced to one-twelfth the natural size. Fig. 661 *a* is one of the large teeth, reduced one-half. They have the Labyrinthine structure explained on p. 280. Fig. 662 represents the prints of the fore and hind feet of a *Chirotherium*, one-twelfth natural size, from a slab obtained at Hildburghausen in Saxony, supposed to be those of a *Labyrinthodon*. The larger track in one was eight inches long, the stride fourteen inches; in another, the length was twelve inches. Similar tracks have been found at Storton Hill in England.

(2.) *Lacertians and Saurians.*—The species of the Trias have biconcave vertebræ, like the Thecodonts and Enaliosaurs (in this approximating to the Fishes). A species of the Permian genus *Thecodontosaurus* is found in the Trias at Leamington, England. The *Rhynchosaur* (*R. articeps* Owen) had the beak of a Turtle, without teeth. *Simosaur*, *Nothosaur*, *Pistosaur*, and *Conchiosaur* are names of

different genera of Swimming Saurians (*Enaliosaurs*) of the Triassic, whose remains occur mostly in the Muschelkalk of Europe, and especially at Luneville,

Figs. 661–663.



REPTILES.—Fig. 661, Skull of Labyrinthodon (Mastodonsaurus) giganteus (× $\frac{1}{12}$); 661 *a*, Tooth of same (× ½); 662, Footprints of Chirotherium (× $\frac{1}{12}$); 663, Footprints of a turtle?.

Beyreuth, and in Upper Silesia. They are distinguished from the Enaliosaurs of the Jurassic by the extraordinarily large temporal, orbitary, and nasal openings through the cranium, which leave little bone. The *Nothosaurus mirabilis* was about seven feet long. The teeth were thin, long, and conical, three to five times as long as broad, striated, slightly inflexed, and inserted in distinct cavities. *Placodus* is another related genus. Two or three *Plesiosaurs* of the Lias (as *P. Hawkinsii* and *P. costatus*) occur in the bone-bed at the very top of the Trias,

Figs. 663 A. 663 B.

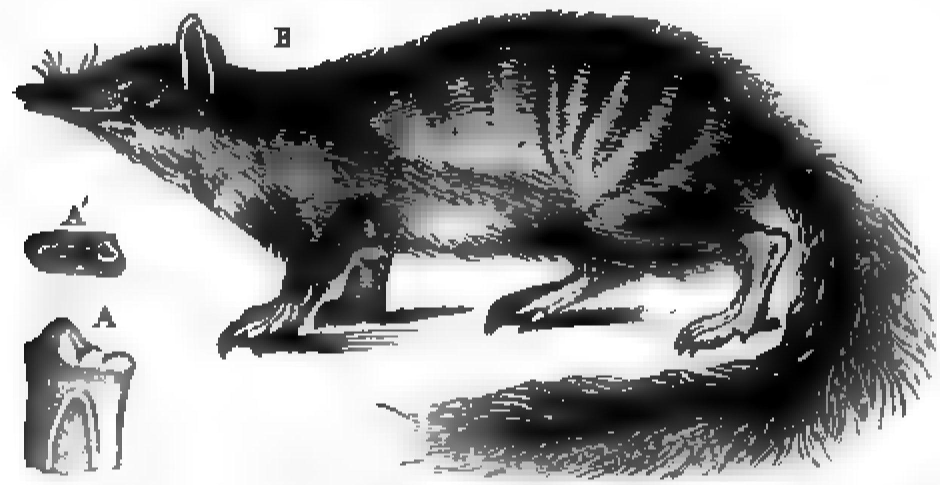


Fig. 663 A, Molar tooth of Microlestes antiquus, side-view; A′, view of crown of same; 663 B, Myrmecobius fasciatus (× ¼).

or base of the Lias, at Aust Cliff in England. Other Triassic Saurians are the *Belodon* of von Meyer (*Phytosaurus* of Jäger), a carnivorous, crocodile-like species,

with the teeth in sockets; and the *Termatosaurus* of Plieninger, from the Keuper of Wurtemberg.

(*c.*) *Turtles.*—A series of tracks like fig. 663 have been observed in Germany which have been referred to a Turtle, the earliest representative of the tribe. The tracks form two *distant* parallel lines, as they should for an animal having a broad shell-covered body and short legs.

Coprolites of Reptiles are also common. Various footprints are described and named in Jardine's Ichnology of Annandale.

(*d.*) *Mammals.*—Fig. 663 A represents the side-view of a tooth of *Microlestes antiquus* Plieninger, from the bone-breccia of Wurtemberg; A′, view of crown. A tooth of the same mammal has been found at Frome, in England. Owen regards the species as probably near the modern *Myrmecobius* and closely related to another extinct Marsupial genus, *Plagiaulax*, found in the English Upper Oolite. Fig. 663 B represents the *Myrmecobius fasciatus*, a species of Marsupial now living in Australia.

Fossils characteristic of the subdivisions of the Trias.

The characteristic fossils of the three subdivisions of the Trias are as follow:—

1. *Lower group.*— *Voltzia heterophylla, Calamites Mougeoti, Placodus impressus, Nothosaurus Schimperi.*

2. *Middle group.*—*Encrinus liliiformis, Avicula ? socialis* (common to all the groups), *Myophoria* (Trigonia) *vulgaris, M. lineata, Terebratula vulgaris, Ceratites nodosus, Pemphix Sueurii, Hybodus Mougeoti, Placodus* (several species), *Nothosaurus* (species differing from those of the lower group), *Simosaurus, Pistosaurus.*

3. *Upper group*, or *Keuper.*—*Equiseta, Calamites arenaceus, Pterophyllum Jægeri, Pt. longifolium, Pt. Munsteri, Estheria* (Posidonia) *Keuperiana, Labyrinthodon giganteus, Belodon, Termatosaurus.*

The *Estheria minuta* ranges through all the divisions.

IV. General Observations.

1. AMERICAN.

General Progress.—The following points bear upon the history of this period:—

I. The position of the rocks in linear ranges, parallel with the mountains, and therefore along depressions in the surface that were made when the Appalachian foldings took place. The Connecticut valley is one of the great synclinal depressions made at that time. Such areas would naturally have become inlets of the sea, or estuaries, river-courses, lakes, or marshes, and would have received the debris of the hills brought in by streams.

II. The absence of Radiates, the paucity of Mollusks, and the

presence of few species that are properly marine. These facts prove that the ocean had imperfect access, where any, to the regions,—that the beds are not sea-shore formations like the Cretaceous and Tertiary of later times; and thus they confirm the idea that the beds are partly of estuary and partly of lacustrine origin. The occurrence of vegetable remains and the coal beds sustain this conclusion.

III. The ripple-marks, raindrop-impressions, and footprints. These show, wherever they occur, that the layer was for the time a half-emerged mud or sand flat; and, as they extend through much of the rock, there is evidence that the layers in general were not formed in deep water. They abound especially in the upper half of the Connecticut-valley strata.

IV. The thickness,—3000 to 5000 feet or more. We learn from this thickness, in connection with the preceding, that the areas underwent a gradual subsidence of 3000 to 5000 feet or beyond; consequently, that these oblong depressions made at the time of the foldings were slowly deepening, and continued to deepen until the last layer was laid down.

V. The tilted and displaced condition of the beds, without evidence of folds. This inclination has been attributed to deposition on a sloping surface. But such cases of oblique deposition are exceptions, and not the general rule; while in the case of the sandstone, the layers are inclined 10 to 30 degrees or more, in each of the great regions. The tilting must, therefore, be a result of mechanical force; and, as faults are not numerous, while joints are common, it follows that the force was very gradual in its action.

Under IV., a profound subsidence was shown to have been in progress in the regions of depression occupied by the strata. Such a subsidence would have brought a strain upon the overlying beds, and sooner or later would have produced fractures and disturbance; and if one side or part of the depression were undergoing more subsidence than the opposite, it would have caused that oblique pushing of the beds that would have ended in faulting and tilting them. The direction of the dip and strike in such a case would depend on the relative positions, with reference to the whole basin, of the parts undergoing greatest and least subsidence.

VI. The sandstone strata intersected by dikes of trap. These dikes are proofs of fracture of the earth's crust; of more fractures in the part of the crust directly beneath the formation than outside of the region; therefore of fractures in the old synclinal depression in progress of subsidence. The subsidence of such a region would bring increasing tension or strain upon the rocks

below, which might ultimate in fractures, especially about the axis of the depression. The tilting, fractures, joints, and ejections of igneous rock are, therefore, parts of one connected series of events.

The manner in which the trap at its eruption has sometimes separated the layers of sandstone, and in this way escaped to the surface, instead of coming up through the fissures simply, shows that the rock had been tilted extensively before the ejection; and, as the trap dikes intersect the later beds of the formation, the igneous ejections were among the later results of the period, if not to a great extent subsequent in time.

It is hence no mystery that rocks of igneous origin are intimately associated with rocks of aqueous origin in these Triassic regions.

Thus the period of these rocks came to a close somewhat similar to that of the Carboniferous age. The Carboniferous age ended in a period of disturbance, escape of heat, as shown in consolidations and metamorphism, and a complete destruction of life along the Continental border; and the period of these sandstones was closed in uplifts, fractures, emissions of heat, consolidations, and destructions of life. But in the former case the crust was yielding, and became folded into mountains: in the latter, the action, though ranging along the same line of coast, from South Carolina to Newfoundland, was more limited; the stiffened crust only yielded by breaking; the heat came out in ejected melted rock, instead of a slow, gentle effusion, and the swelling up of the lava and simple tiltings of the strata formed hills and ridges. The destruction of life was in both cases complete.

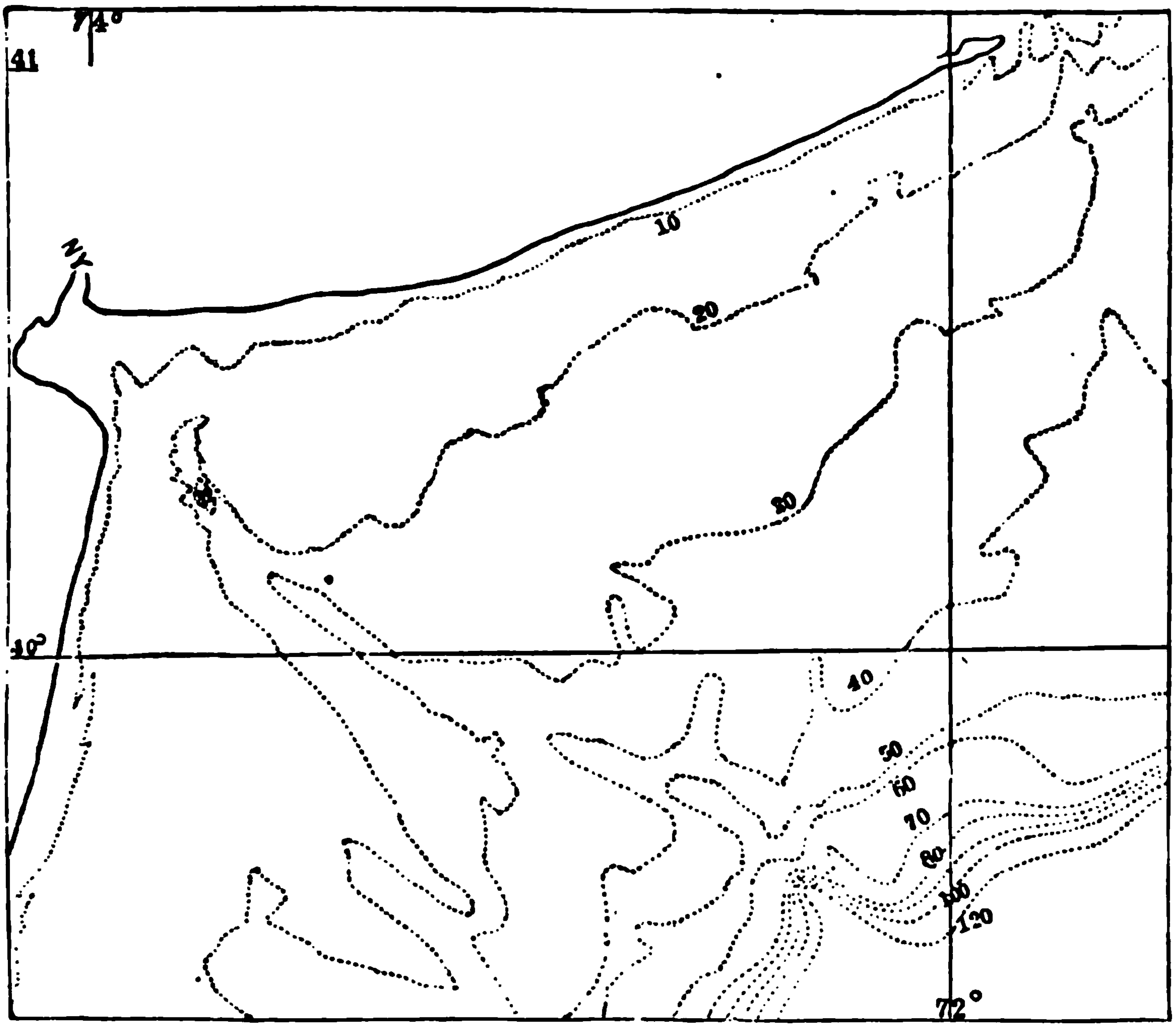
Life of the Period.—The steps of progress in the life of the globe, as the Mesozoic era opened in the Triassic period, were especially important. The storing away as coal of the excess of atmospheric carbon had purified the atmosphere; and soon after the close of Palæozoic time—whose great feature was that its animal life had made rocks, and its plants, coal—we find higher races breathing the better air. Saurians become numerous; and the vertebrate type expands by the appearance of the new classes Birds and Mammals. Among these types, the Saurian continues rapidly to rise in perfection with the following period of the age; while the birds and mammals remain of inferior types, forerunners of an age of higher progress.

Geography.—The position of the Triassic beds on the Atlantic border shows that this part of the continent stood nearly at its present level. The strange absence of Atlantic sea-shore deposits in the Triassic period may be accounted for by supposing that the

dry land stretched farther out to the eastward, and that the sea-shore deposits were formed, but are now submerged. A change of level of five hundred feet would take a breadth of eighty miles from the ocean and add it to the continent.

This important fact—which has been before referred to more than once, on account of its bearing on the history of the continent—is presented to the eye in the accompanying map, copied from one

Fig. 664.



Map of the submerged border of the continent off New Jersey and Long Island, with lines of equal soundings in fathoms; NY, City of New York.

of the charts of the Coast Survey under Professor Bache. The coast-line on the north is the south shore of Long Island; that on the west, the coast of New Jersey; while the Bay of New York (at the mouth of the Hudson) is near the junction of the two (below NY). The dotted lines are lines of equal soundings, indicating depths of 10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 120 fathoms. These lines run back in a long loop northwestward towards New York

harbor, showing deeper water along this line, and evidently proving that once the land was above water, with the Hudson River occupying this channel on its way to the ocean. At two or three places along this channel there are "deep holes," as they are called (one of them at 32, where the depth is thirty-two fathoms), which may have been former sites of New York harbor; for the waters of the harbor are now about six fathoms deeper than those about its entrance.

This border, now submerged, has, therefore, in former time been dry land; it may have been partly so in the Triassic period, and thus have caused the imperfect connection of the Triassic areas of the Atlantic border with the ocean.

The Triassic continent spread westward to Kansas, and southward to Alabama; for through this great area there are no rocks more recent than the Palæozoic.

The Triassic beds beyond the Mississippi are remarkable for their great extent and their paucity of life. They occur in western Kansas on the east, and along the Little Colorado west, of the mountains; and they have been observed at many points between these distant meridians: it is therefore probable that they cover a large part of the slopes of the mountains beneath the Cretaceous and Tertiary rocks of the surface. The discovery of animal fossils may yet be made in some part of this region. Yet it is remarkable that the beds should have afforded thus far no relics of marine life, unless the Saurian remains be an exception.

There appears to be but one mode of accounting for the formation of such deposits over this wide territory. The interior sea in which the Carboniferous limestone of the preceding age—even wider in its limits—had been formed, must have become more shallow and have been cut off to a great extent from free communication with the ocean. Such a shallow salt sea, alternately freshened and concentrated by the successive rains and droughts of a season, would be quite unfit for ordinary marine life. Few species could survive through such alternations; and hence there would be necessarily a paucity of fossils in the deposits. Examples of such interior salt seas without marine life now exist. Lake Utah is one, in the Rocky Mountains. A complete evaporation over any portions would have deposited salt and gypsum,—the salt to be dissolved and carried off wherever the region admitted of drainage by outflowing waters, the gypsum to remain in the beds.

Facts observed among the Pacific Coral islands, illustrating the destruction of life alluded to, have been mentioned on page 250. These islands exemplify also the origin of the gypsum. According

to A. Hague, there is a deposit of gypsum, two feet thick, on Jarvis Island, overlying the coral sands of the old lagoon, and others similar also on Starbuck's, McKean's, and Phœnix Islands. He attributes the formation of the deposits to the repeated evaporation of sea-water, long re-supplied by the tides, over the area of the lagoon, during the time when it was gradually being recovered from the ocean.

Climate.—There are no data yet obtained for comparing the climate of the Arctic in the Triassic period with that of the Temperate United States.

In the preceding pages, the beds and the period they represent have been called *Triassic.* Yet it is to be understood that they are probably in part Jurassic.

2. Foreign.

The occurrence of ripple-marks throughout most of the European Triassic sandstones and marls, and also raindrop-impressions and cracks from drying, show that the beds are of shallow-water and mud-flat origin; and the salt—as explained on p. 249—indicates that there were flats exposed to occasional inundations of the sea, where the salt water evaporated. The kinds of rock are similar to those of the Saliferous region in central New York, although they belong to very different periods: the history of one is probably essentially that of the other.

The fossiliferous limestone (Muschelkalk) of the Middle Trias in Germany indicates that in that region there was for a while an interval of somewhat deeper waters.

As the alternations in these beds depend on small changes of level over limited areas, there is sufficient reason for their not occurring in other regions.

Appendix.—In Asia and Australia there are coal beds of considerable extent, which have been referred to different periods from the Carboniferous to the Jurassic. The Asiatic deposits occur at Burdwan in western Bengal, where they are extensively worked, and about Nagpur in the Deccan, India. In Australia they cover a large surface in New South Wales, extending inland from the coast.

The fossil plants of the first region are species of *Pecopteris*, *Glossopteris* (an oblong simple-leaved fern), *Tæniopteris*, *Vertebraria* (stems of unknown relations), *Phyllotheca* (of the Equisetum tribe), *Zamites*, etc. About Nagpur nearly the same genera and partly the same species occur, excepting the Cycads. In the Australian beds there is a similar resemblance to the Burdwan coal field.

On account of the absence of the peculiarly Carboniferous genera in both the Asiatic and Australian beds, and the general similarity of their flora, while

at the same time the Bengal beds contain Cycads, the coal has been referred by most authors to the Mesozoic, and either the Jurassic or Triassic period.

In the Australian beds there are heterocercal Ganoids; and hence the formation cannot be more recent than the Triassic.* Sixty miles south of Nagpur, at Mangali, beds similar to those of Nagpur occur, which have been referred to the same period, although there are no plants to demonstrate positive identity; they contain *Estherias*, homocercal *Ganoids*, and a species of *Labyrinthodont*,—evidently a Triassic assemblage of species.

In view of all the facts, it appears probable that the coal beds referred to, both in Asia and Australia, represent the *Triassic* period.

There are other beds at Kota on the Pranhita, related to those of Mangali. There are still others at the Rajmahal Hills, in central India, the age of which is more doubtful. They abound in Cycads, and fail of most of the genera found at Nagpur: they have been regarded as Jurassic.

JURASSIC PERIOD (17).

The Jurassic period derives its name from the Jura Mountains on the western borders of Switzerland, one of the regions characterized by the formation.

1. AMERICAN.

I. Rocks: kinds and distribution.

On the *Atlantic border*, the upper portion of the formation described in the preceding pages on the Triassic may belong, as has been observed, to the Jurassic period. As no species of fossils characteristic of any part of this period have yet been found in the beds, there is some doubt on this point. The absence of *Trigonias*, *Belemnites*, *Ammonites*, and other Jurassic forms, may, however, be owing to the fact that the strata are not properly of sea-shore origin.

On the *Gulf border* there are no rocks of this period anywhere exposed to view.

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* The author, in his notes on Australian Geology, published in his Exploring Expedition Geological Report (in which one of the Ganoids and many of the coal plants are figured and described), referred the Australian beds to the Permian period, on account of the presence of the heterocercal Ganoids, the absence of Cycads, and the regular continuity of the beds with the Carboniferous strata below. But the resemblance to the Indian flora must bring all to one horizon, and the above conclusion seems best to harmonize the facts. Rev. W. B. Clarke reports true Lepidodendra from the interior of New South Wales,—from which it appears that the Carboniferous flora is represented on the Australian continent.

In the *Western Interior region*, the Jurassic period may claim a part —perhaps a large part—of the gypsiferous beds already described: here, again, fossils are wanting to decide the question of age.

But, apart from these doubtful beds, there are true Jurassic strata full of fossils, overlying in many places the gypsiferous marls and sandstone. They have been observed about the Black Hills and the Laramie Mountains, and also at the base of other ridges in the Rocky Mountains. The beds consist of impure limestone with layers of marl.

In the *Arctic region*, also, there are a number of localities of fossiliferous Jurassic strata.

The discovery and identification of the Jurassic of the Black Hills of Dakota were made by Hayden & Meek. The rocks occur also at Red Buttes on the North Platte, west of the Black Hills; also along the southwest side of the Big Horn Mountains (43½° N., 108° W.), and the northeast side of the Wind River Mountains; also beyond the Wind River Mountains, on the west; also about the head-waters of the Missouri:—at all of which places fossils occur. (Hayden.) Another locality is near the valley of Green River, east of Lake Utah (Great Salt Lake), as announced by Meek & Engelmann.

The rocks observed are in general a gray or whitish marly or arenaceous limestone, with occasional purer compact limestone beds, intercalated with laminated marls. The thickness at the Black Hills is about 200 feet; on the northeast of the Wind River Mountains, 800 to 1000 feet; about Long's Peak, where the marls are absent, 50 to 100 feet.

The Arctic localities are—the eastern shores of Prince Patrick's Land, in 76° 20′ N., 117° 20′ W.; the islands Exmouth and Talbe, north of Grinnell Land, 77° 10′ N., 95° W.; and Katmai Bay, or Cook's Inlet, in Northwest America, 60° N., 151° W.

II. Life.

Although but little is yet known of the life in America of the Jurassic period, several genera of Radiates and Mollusks which mark the Jurassic beds of Europe have here been found, the most prominent of which are *Pentacrinus*, *Trigonia*, *Ammonites*, and *Belemnites*. The characteristics of Belemnites and Ammonites are briefly mentioned on p. 156, and again beyond, on pp. 450, 451.

Characteristic Species.

No plants have been described, except a few by Newberry from a coal seam in the gypsiferous sandstone of the Upper Colorado, in the Moqui country (near the meridian of 111°), the age of which is doubtful (p. 417). The observed genera are *Cyclopteris*, *Pecopteris*, *Neuropteris*, *Sphenopteris*, and *Clathropteris*.

The *Clathropteris* from near the middle of the Connecticut River sandstone (fig. 628, p. 419), as suggested by Hitchcock, is some evidence—though far from

decisive—for referring the upper half of that formation to the Jurassic. The European species of this genus occur in the Lias and Trias.

The species of Radiates and Mollusks here figured were collected at the Black Hills.

1. **Radiates.**—*Fig.* 665, a joint of the stem of *Pentacrinus Asteriscus*, a Crinoid with a pentagonal column.

2. **Mollusks.**—(*a.*) *Conchifers.*—Fig. 666, *Monotis curta;* fig. 667, *Trigonia Conradi;* 668, *Tancredia Warreniana.* (*b.*) *Cephalopods.*—Fig. 669, young specimen of *Ammonites cordiformis;* fig. 669 *a*, side-view of the same; fig. 670, *Belemnites densus*, the upper part broken away.

Figs. 665–670.

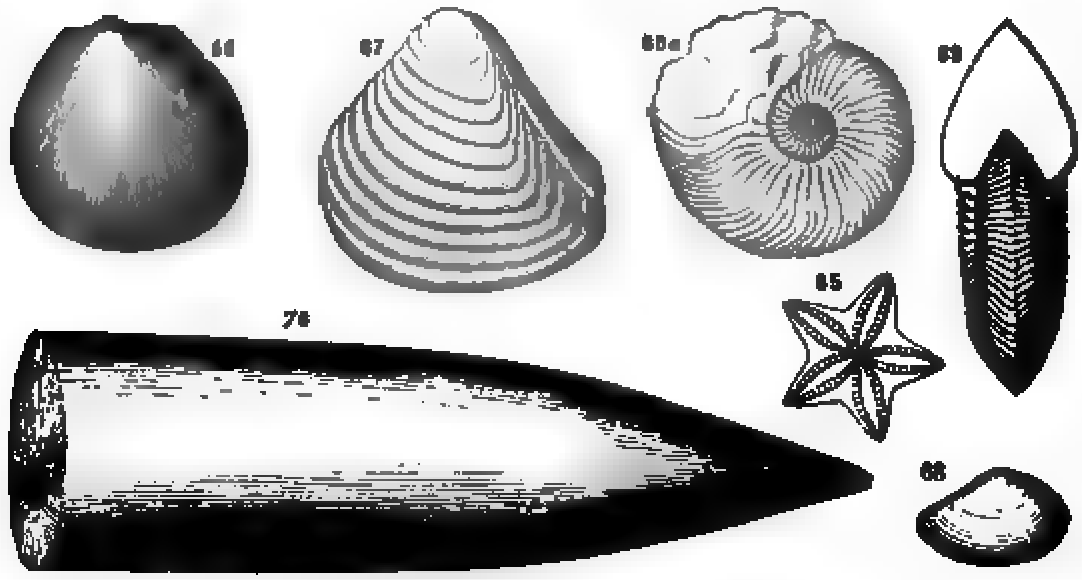


Fig. 665, A segment of the column of Pentacrinus asteriscus; 666, Monotis curta; 667, Trigonia Conradi; 668, Tancredia Warreniana, 669, Ammonites cordiformis; 669 *a*, Side-view of same, a little reduced; 670, Belemnites densus.

Among the Arctic fossils of this period, there are at Prince Patrick's Land *Ammonites M'Clintocki*, a species near *A. concavus* of the Lower Oolite; and at Cook's Inlet, *Ammonites Wosnessenski, A. biplex?, Belemnites paxillosus*, and *Unio Liassinus*. *A. biplex* also is reported to occur in the Chilian Andes, in latitude 34° S., and probably also in Peru near the equator, as well as in Britain and Europe.

2. FOREIGN.

I. Rocks: kinds and distribution.

The strata of the Jurassic period in England (see map, page 354, on which the areas numbered 7, 8, are Jurassic) appear at the surface over a narrow range of country (averaging thirty miles in width) commencing at Lyme-Regis and Portland on the British Channel.

and extending across England, north of northwest, to the river Humber, and still farther north, on the eastern coast of Yorkshire, almost to the mouth of the Tees. They thus cover eastern England; while the western part, from the north to Cornwall, was apparently an elevated barrier against the ocean. Jurassic beds also occur on the northeast coast of Ireland, as at the Giants' Causeway, and on the Western Isles.

Following the line of the British Jurassic belt from Lyme-Regis and Portland across the English Channel, we come upon an apparent continuation of the belt in France. It sweeps south by the borders of Brittany to the central plateau of France, and then east and north by the eastern boundary of the empire, thus surrounding a large area of which Paris is the centre.

The line of barrier-islands of western England is continued in Brittany in western France; the line of the outcropping Jurassic, in similar outcropping Jurassic in France; and the area of the shallow Jurassic sea over eastern England, in the extensive Parisian basin,—a sea which was then the western and southern border of the German Ocean and covered what are now the sites of London and Paris.

The central plateau of France—a region of crystalline rocks—is nearly encircled by Jurassic strata, and the rocks are continued eastward over the Jura Mountains (by Neufchatel) and along their continuation through Wurtemberg and Bavaria in southern Germany. They appear also in northern Germany (Westphalia) and the Alps (Savoy, etc.).

Jurassic beds occur also along the Andes in many regions, from their northern limit to Tierra del Fuego. They are found in many parts of Asia, and have been recognized by W. B. Clarke in Australia.

The Jurassic period in England and Europe is divided into three epochs: (1) the epoch of the Lias, or the Liassic, so designated from a provincial name of the rocks in England (No. 7 *a* on the map referred to); (2) the epoch of the *Oolite*, or the *Oolitic* (No. 7 *b*), so called because a prominent rock of the series in England is *Oolite* (see p. 85); and (3) the epoch of the *Wealden* (No. 8 on map), named from a region called The Weald, in Kent, Surrey, and Sussex, where the beds were first studied.

The *Liassic* beds consist mainly of grayish limestones, containing marine fossils.

The *Oolitic* include other limestones, part of which are oolitic in texture, along with arenaceous and clayey strata in many alternations. One of the limestones is a coral-reef rock. All of the beds are of marine or sea-shore origin, as the fossils show, excepting strata in the local Purbeck beds near the top of the series, one of which, on the island of Portland, is called the Portland dirt-bed.

The *Wealden* is wholly of estuary or fresh-water origin; the beds consist of clays, sands, and, to a small extent, limestone.

The prominent subdivisions of the Jurassic formation observed in England (though not present alike in all its Jurassic regions) are the following, beginning below:—

I. Lias.

1. *Lower Lias:* consisting of grayish laminated limestone, with shale above, and a bone-bed and marls below.
2. *Middle Lias:* a coarse shelly limestone called marlstone.
3. *Upper Lias:* beds of clay or shale with some thin limestone layers.

II. Oolite.

1. *Lower* or *Bath Oolite*, consisting of—
   (1.) The *inferior Oolite*, a limestone with fossils and layers of sand.
   (2.) *Fuller's-earth* group, or clayey layers.
   (3.) The *Great Oolite*, limestone mostly oolitic.
   (4.) *Forest-marble* group, sandy and clayey layers, with some oolite.
   (5.) *Cornbrash*, a coarse shelly limestone.

The *Stonesfield slates*, noted for their remains of Saurians, as well as of the earliest British mammals, and also of insects and other species, occur near Oxford in England, and belong to the Lower Oolite, below the Great Oolite.

At Brora, in Sutherlandshire, there is a bed of oolitic coal of good quality, three and a half feet thick, which has been long worked: it is covered by several feet more of impure coal containing pyrites. It is supposed to belong with the Great Oolite.

2. *Middle* or *Oxford Oolite:* consisting of—
   (1.) The *Kelloway Rock*, a calcareous grit, overlying blue clay, and overlaid by the *Oxford clay.*
   (2.) Calcareous grit and oolitic coral limestone, called the *Coral Rag.*
3. *Upper* or *Portland Oolite:* consisting of—
   (1.) *Kimmeridge Clay.*
   (2.) *Shotover Sand*, a calcareous rock with concretions.
   (3.) The *Portland Oolite.*
4. *Purbeck beds:* consisting of (1) the *Lower Purbeck*, fresh-water marls with the "Portland dirt-bed," and resting on the upper layers of the Portland stone; (2) the *Middle Purbeck*, mostly a bed of marine limestone, 30 feet thick; (3) the *Upper Purbeck*, 50 feet of fresh-water deposits. The dirt-bed of the Purbeck is the second deposit affording remains of British mammals. It contains also numerous remains of Cycads, etc.

III. Wealden.

1. *Hastings Sands:* sandstone with some clayey and limestone layers, containing Saurian remains, fluviatile shells, etc.
2. *Weald Clay:* clayey layers, with some calcareous beds containing fresh-water shells.

The British subdivisions are for the most part recognized in France, and have received special names by D'Orbigny. They are (I.) in the Lias,—1, the

Sinemurian (Lower Lias, named from the locality at Sémur); 2, *Liasian* (Middle Lias); 3, *Toarcian* (from the locality at Thouars); (II.) in the OOLITE,—1, *Bajocian* (the inferior part of the Lower Oolite, named from the locality at Bayeux); 2, *Bathonian* (the Great Oolite, Bath Oolite); 3, *Callovian* (Kelloway Rock); 4, *Oxfordian* (Oxford Clay); 5, *Corallian* (Coral Rag); 6, *Kimmeridgian* (Kimmeridge Clay); 7, *Portlandian* (Portland Oolite).

In the French Juras the most of the above subdivisions may be traced. There are,—

1. The Lower Lias,—a Lias limestone, called also Gryphite limestone, from the abundance of the fossil *Gryphæa arcuata*; 2, the Middle Lias, marls; 3, the Upper Lias, bituminous schists, in some places called Posidonia schists, from the abundance of *Posidonia Bronnii*, with a rough limestone above. The Lias is overlaid by (1) the Lower Oolite; (2) the Oxford Oolite; (3) the Coral and Astarte limestone, and Portland beds.

The famous beds of *Lithographic slate* at Solenhofen, affording remains of many Insects, several species of Saurians, seven of Pterodactyls, etc., are situated in the district of Pappenheim in Bavaria, and are of the age of the Middle Oolite, or that of the Coral Limestone.

II. Life.

1. *Plants.*

The land-plants of the Jurassic period are mainly *Ferns*, *Conifers*, and *Cycads*, as in the Triassic. Leaves and stems are found in many

Figs. 671–673.

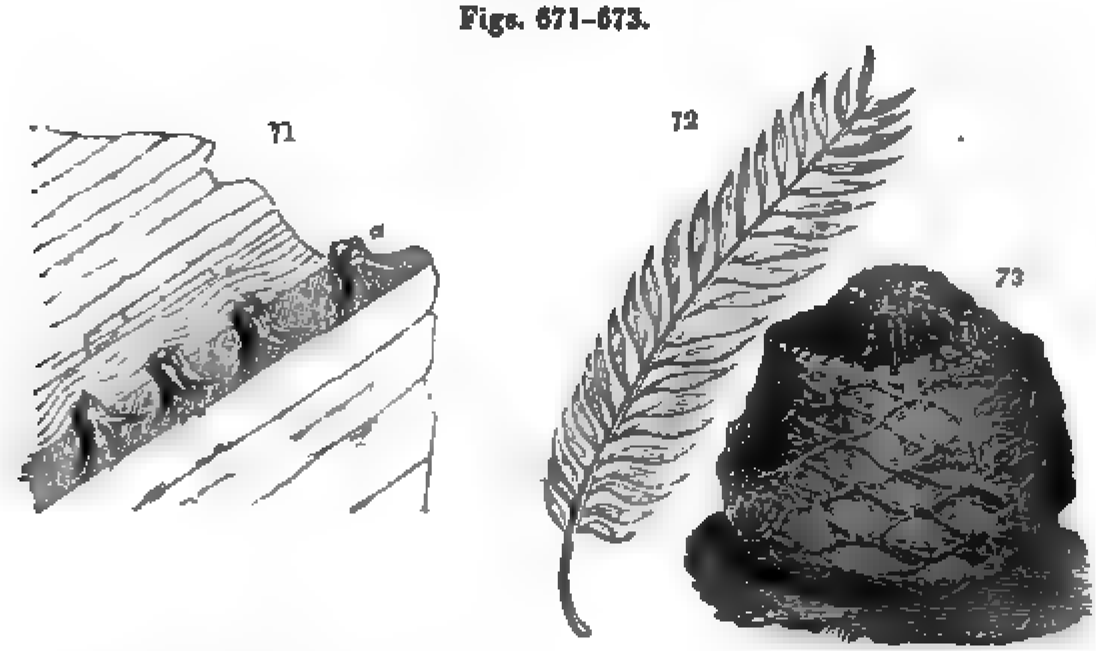


Fig. 671, section from near Lullworth Cove, showing stumps of trees (*a*) in the Portland "dirt-bed;" 672, Leaf of a living Zamia (× $\frac{1}{30}$); 673, stump of the Cycad Mantellia (Cycadeoidea) megalophylla (× $\frac{1}{30}$).

of the strata, and remains of a forest in what is called the Portland dirt-bed (fig. 671) (lower part of the Purbeck), the trees of which

were Conifers and Cycads. Fig. 673 represents one of the Cycad stumps, and fig. 672 is the leaf of a modern *Zamia*, which those of the Mantellia probably resembled. Near Whitby, on the sea-coast of Yorkshire, and in the Stonesfield slate, fossil ferns are common.

No Jurassic *Angiosperms* are known.

2. *Animals.*

The *Radiates* include a number of Crinoids, mostly of the genera *Pentacrinus* and *Apiocrinus* (fig. 720); also a variety of Corals (figs. 717–719), Star-fish (fig. 721), and Echinoids (figs. 694, 722, 722 *a*), having in general a modern aspect, though of extinct species and mostly of extinct genera.

Among *Mollusks* there is a great variety of new forms, many peculiar to the Mesozoic era. The last of the Brachiopods of the *Spirifer* and *Leptæna* families appear in the Lias (figs. 696–697). These Leptænas are minute species (fig. 696 *a*), contrasting wonderfully with the abundant and large Leptænas of the Silurian, when the family was at its maximum. The prevailing Brachiopods are of the modern genera *Terebratula* and *Rhynchonella*.

Conchifers comprise several new genera. *Gryphæa*, of the Oyster family, having an incurved beak, commences in the Lias; and *Exogyra*, another of the family, with the beak curved to one side, begins in the Oolite. *Trigonia*, a triangular shell (successor to *Myophoria* of the Triassic and *Schizodus* of the Permian), appears in the Lias.

The Gasteropods are represented by several new modern genera, besides others that are now extinct. But the type of Cephalopods especially undergoes great expansion. The genus *Ammonites*, of Triassic origin, abounds in species (figs. 700, 701). The shell of the Ammonite has the septa or partitions flat over the middle, but flexed or plicated in a complex manner at the margin: in an upper view of a septum it seems to be bordered by a few large holes, each of which is a ramified pocket made by the flexure of the margin. The animal lived in the outer chamber of the shell; but the mantle descended into the cavities, and thus it is assisted in holding to its shell. The siphuncle differs from that of the Nautilus family in being dorsal. In some species the aperture of the shell had the simple form in fig. 730; in others it was prolonged as in fig. 731. Over 300 species lived in the Jurassic, besides many Nautili.

In addition to these Cephalopods with external chambered shells (Tetrabranchs or Tentaculifers, p. 156), there were also those having an internal shell or bone (Dibranchs or Acetabulifers), a group

which includes very nearly all known existing species. Among them the most abundant is the *Belemnite*. The fossil is a cylindrical stony body (fig. 670), radiated in structure, having a conical cavity (or *alveolus*). The lower part of the cavity, in perfect specimens, is occupied by a small chambered cone, called the *phragmocone*, which has a siphuncle. When unbroken (which is very seldom), the osselet has a thin expansion above on one or two sides, which is sometimes much prolonged. One form of it is shown in figs. 702, 703. The Cephalopod was much like a *Sepia*. Fig. 732 represents the animal of an allied genus called *Acanthoteuthis*. There were also species of the Sepia or Cuttle-fish family, and Calamaries, or Squids; and the ink-bags of these species (fig. 706) are sometimes found fossil, and also the smaller ones of Belemnites. Buckland states that he had drawings of the remains of extinct species of Sepia made with their own ink.

The sub-kingdom of Articulates is represented by various Worms, Crustaceans, Spiders, and Insects; and of the last, all the principal tribes appear to have been represented, even to the highest, the Hymenopters. Figs. 734, 735, are Crustaceans of the Oolite; 733, 736, remains of Insects. Fig. 733 is a Dragon-fly, or *Libellula* (Neuropter); fig. 736, the wing-case of a beetle (Coleopter). Fig. 737 is the earliest known of true Spiders,—for the only Carboniferous species of the class are Scorpions. It is from Solenhofen.

Vertebrates present no marked progress in the class of fishes: there are only Ganoids and Selachians; and none of the former have vertebrated tails, this Palæozoic feature finally disappearing. The Reptilian type, on the contrary, undergoes an expansion more remarkable than that of Cephalopods. There are no Labyrinthodonts. But the true Reptiles come forth in numerous Enaliosaurs (sea-saurians, p. 346) of higher grade than the Simosaurs of the Triassic, as is shown in their solid bony skulls; in Lacertians and Crocodilians, many of which were 15 to 50 feet in length; in great Dinosaurs, the highest of Reptiles; in Flying Saurians (Pterosaurs), having wings much like bats; in Turtles of several genera.

The more common genera of Enaliosaurs are *Ichthyosaurus*, *Plesiosaurus*, and *Pliosaurus*. The Ichthyosaurs were gigantic animals, 10 to 40 feet long, having paddles somewhat like the whale (fig. 708), long head and jaws, numerous (in some species 200) stout, conical, striated teeth, an eye of enormous dimensions, thin disk-shaped biconcave vertebræ (figs. 710, 710 *a*). The *I. communis*, found in the Lias of Lyme-Regis and elsewhere, was 28 or 30 feet long. More than thirty species are known to have existed in the Reptilian age.

The *Plesiosaur* (figs. 712, 715) had a long, snake-like neck consisting of twenty to forty vertebræ, a small head, short body, paddles, and biconcave vertebræ differing little in length and breadth. *P. dolichodeirus* (fig. 712) was 25 to 30 feet long. *P. macrocephalus* is represented in fig. 715 just as it lay in the rocks. The British rocks of the Jurassic and Cretaceous periods have afforded sixteen species of Plesiosaurs; and in all twenty-one are known, of which twelve were found in the Lias and seven in the Oolite. The *Pliosaur* is another swimming Saurian, near the Plesiosaur: some individuals were 30 to 40 feet long. Remains of more than fifty species of Jurassic Enaliosaurs have been found in the rocks.

Many of the Crocodilians were of the Teleosaur type, having slender jaws like the Gavial, and also biconcave vertebræ,—the latter a mark both of antiquity and inferiority. Fig. 714 represents the skull of one of these species, the *Mystriosaur*.

The Dinosaurs (p. 346) attained in some species a length of 50 or 60 feet. Unlike all other Reptiles, the sacrum corresponded to five combined vertebræ, as in the higher Mammals. The *Megalosaurus Bucklandi* was about 30 feet long; the teeth were flattened and curved, with trenchant edges, and were set in sockets: a horizontal section of one is shown in fig. 740. It was a terrestrial carnivorous Saurian.

The *Iguanodon* of Mantell was an herbivorous Dinosaur, and had the habit of a Hippopotamus. It was 30 feet long, and of great bulk: the femur, or thigh-bone, in a large individual was about 33 inches long, and the humerus 19 inches; the teeth (fig. 745) were flat, and had a serrated cutting edge like the teeth of the Iguana; and the jaws had some lateral motion,—indicative of its herbivorous character. Many of the teeth from old animals are worn off short. The remains occur in the Wealden of Tilgate Forest, and in the Kentish Rag near Maidstone.

The *Hylæosaur*, another Tilgate Forest Dinosaur, had its skin covered with circular or elliptical plates, and was 20 to 22 feet long.

The Pterosaurs belong mostly to the genus *Pterodactyl*. Fig. 739 represents the skeleton (reduced in size) of *P. crassirostris*, showing the forearm, with the outer finger excessively prolonged for supporting the wing, while the other fingers are free for clinging or grasping. The species was a foot in length, and the spread of the wings was about three feet. As in birds, the bones of Pterodactyls are hollow to fit them for flying; but, unlike birds, they had the skin, claws, and teeth of reptiles. Their habits were probably those of bats rather than birds. They are found mostly in the Oolite and

Chalk, and one in the Lias. Solenhofen has afforded a number of species.

The Mammals of the Jurassic have been found in the Lower Oolite at Stonesfield, and in the Upper Oolite in the Portland "dirt-bed" of the Lower Purbeck.

The relics from the Stonesfield slate are referred by Owen to Marsupials. Fig. 741 represents the jawbone of the *Amphitherium* (Thylacotherium) *Prodeniii*, and fig. 742, the same of the *Phascolotherium Bucklandi*,—each twice the size of nature. The form of the latter jaw is like that in the Carnivorous Marsupials (especially the Thyalacini). The former species, according to Owen, is most nearly related to the Marsupial Insectivores. Two species of *Amphitherium* have been found at Stonesfield.

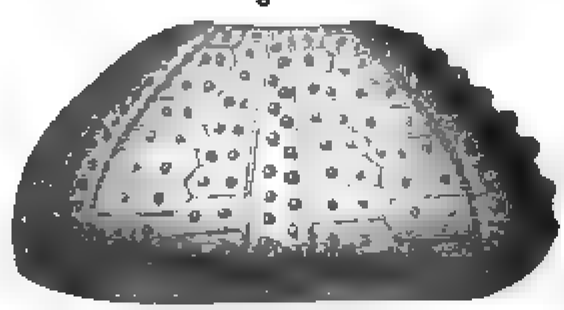
The Portland "dirt-bed" has afforded relics of about fourteen species of Mammals, along with fresh-water shells and insects. The species have been referred mostly to the Marsupials, and but one or two to the Non-marsupial Insectivores.

Characteristic Species.

1. *Liassic Epoch.*

1. Radiates.—*Pentacrinus Briareus*, from the Middle Lias; Star-fish of different types, including that of the *Ophiura*. Fig. 694, *Diadema seriale*, from the Lower Lias. Also species of *Cidaris* and *Hemicidaris*.

Fig. 694.



ECHINODERM.—Diadema seriale.

2. Mollusks.—(*a.*) *Brachiopods.*—Fig. 695, *Leptæna Moorei*, from the Upper Lias, interior of ventral valve, enlarged; fig. 696, dorsal valve of same; fig. 696 *a*, same, natural size; fig. 697, *Spirifer Walcotti*, from the Lower Lias.

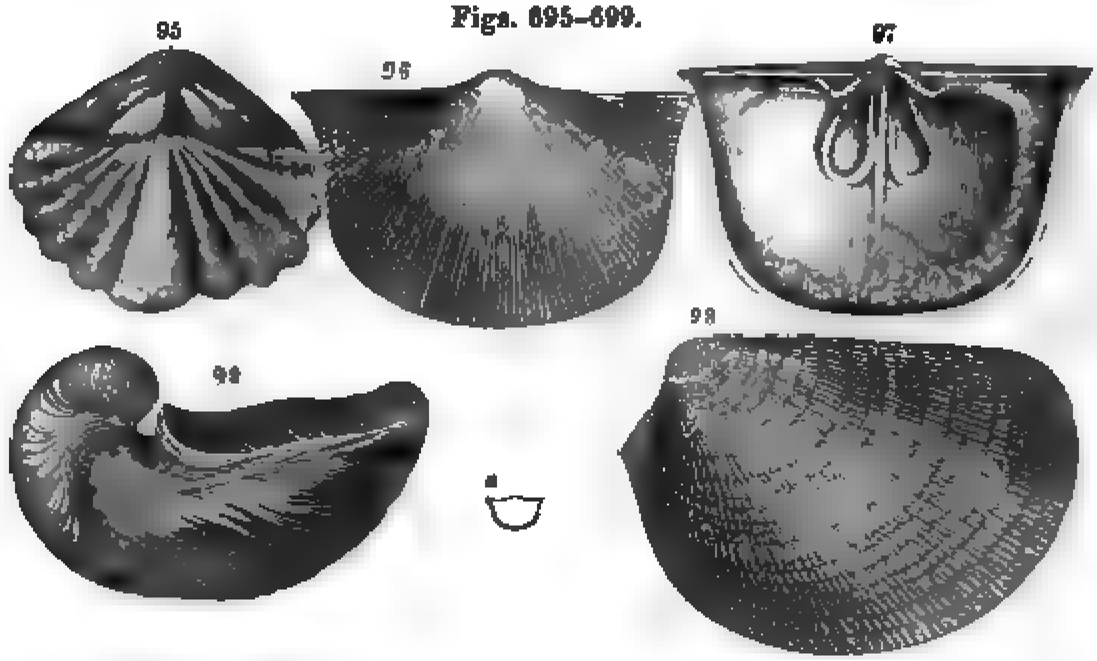
Five species of *Leptæna*, and about twice as many *Spirifers*, occur in the Lias. While these old Silurian genera are disappearing, the new Brachiopod genus *Thecidea* begins, and with it there are a few *Lingulæ*, *Rhynchonellæ*, and *Craniæ*, and many *Terebratulæ*. The genera *Lingula*, *Rhynchonella*, and *Crania*, it should be remembered, are lines reaching from the Silurian to the present time, and *Terebratula* is another genus dating back to the Devonian.

(*b.*) *Conchifers.*—Fig. 699, *Gryphæa arcuata*, especially characteristic of the Lower Lias or Gryphite limestone; *Gryphæa Cymbium*, of the Middle Lias; *Hippopodium ponderosum*; fig. 698, *Ctenoides gigantea*. Other genera are *Pholas*, *Anatina*, *Pholadomya*, *Leda*, *Cytherea*, etc.

(*c.*) *Gasteropods.*—The genera *Pteroceras*, *Planorbis*, *Paludina*, *Melania*, *Nerita*, etc., are supposed to begin here.

(*d.*) *Cephalopods.*—*Tetrabranchs.*—Fig. 700, *Ammonites Nodotianus*, from the Lower Lias: figs. 701, 701 *a*, *A. bisulcatus*, from the Lower Lias; *A. margaritatus*, Middle Lias. *Dibranchs.*—Figs. 702, 703, different views of one of the forms

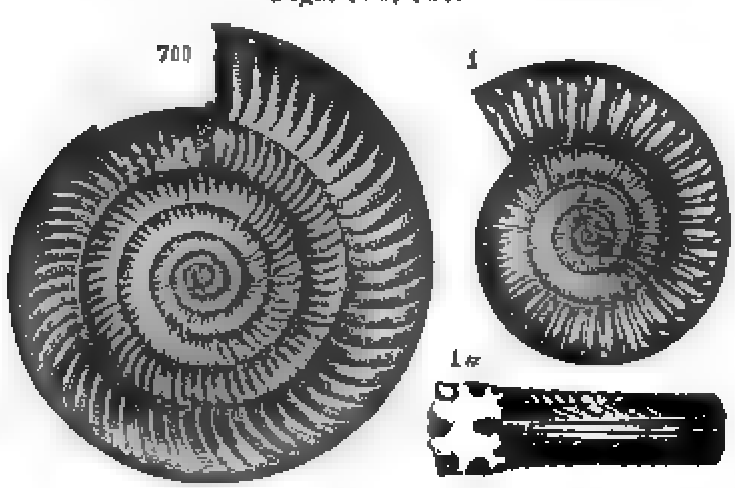
Figs. 695–699.



BRACHIOPODS and CONCHIFERS.—Figs. 695, 696, Leptæna Moorei (× 7); 696 *a*, same, natural size; 697, Spirifer Walcotti; 698, Ctenoides (Plagiostoma) gigantea (× ⅓); 699, Gryphæa arcuata (× ⅔).

of a complete osselet of a Belemnite; fig. 704, *B. paxillosus*, Middle Lias; fig. 704 *a*, section of same near the extremity; fig. 705, *B. pistilliformis*.—Also spe-

Figs. 700, 701.

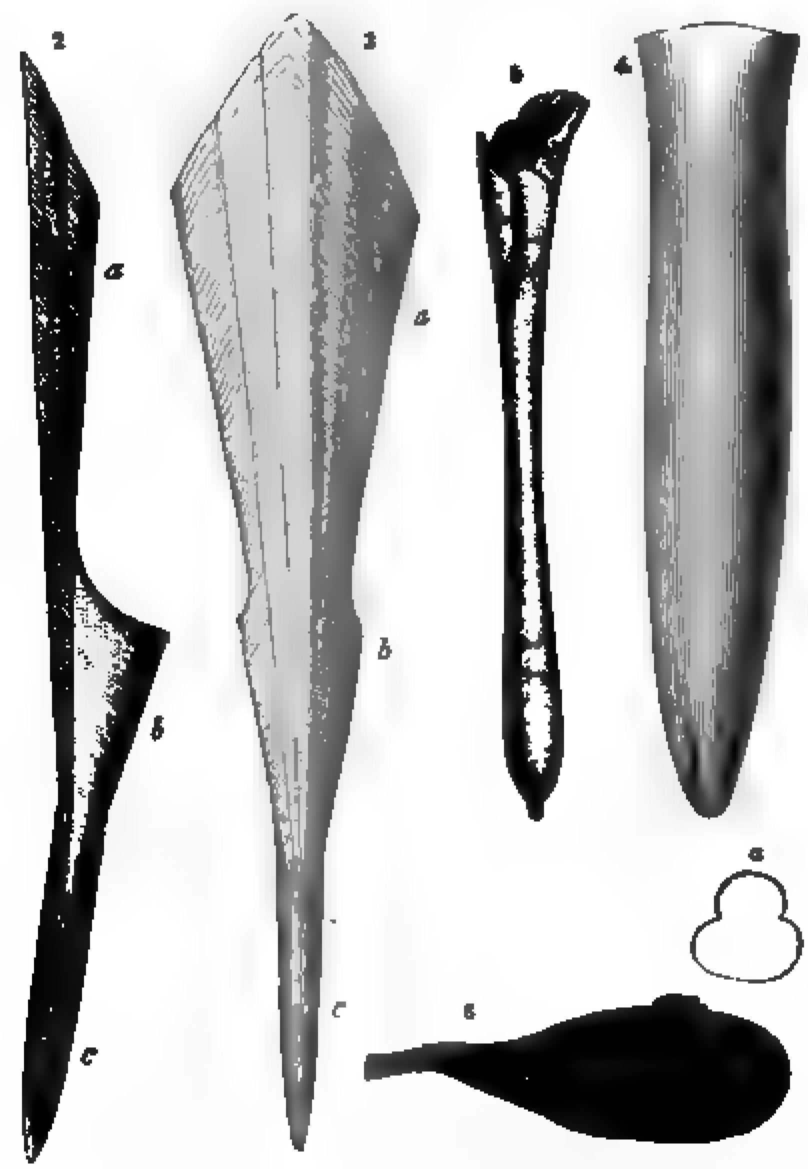


CEPHALOPODS.—Fig. 700, Ammonites Nodotianus; 701, 701 *a*, A. bisulcatus.

cies of the *Calamary* family, or *Teuthids* (having the osselet membranous), of the genera *Beloteuthis*, *Geoteuthis*, etc.: the fossils are the osselet, ink-bag (fig. 706), and horny claws or hooks from the arms.

The last species of the genus *Conularia* occurs in the Lias. The beak-like mandibles (jaws) of Cephalopods are sometimes found fossil, and go under the name of ***Rhyncholites.***

Figs. 702–706.



CEPHALOPODS.—Fig. 702, View, reduced, of the complete osselet of a Belemnite,—side-view; 703, Dorsal view of same; 704, *a*, B. paxillosus; 705, B. pistilliformis; 706, Ink-bag.

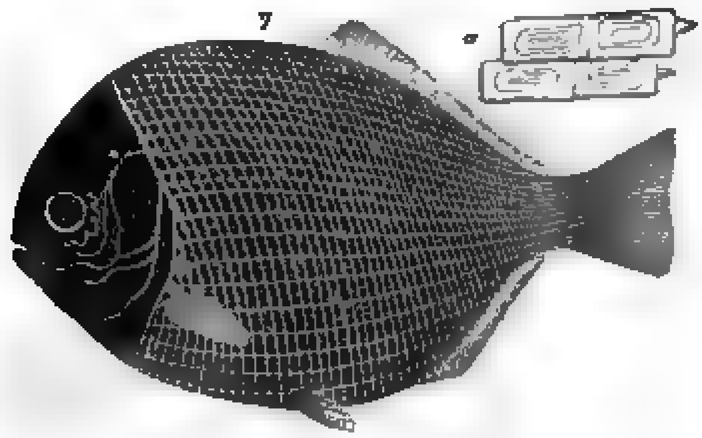
3. **Articulates.**—(*a.*) *Crustaceans.*—Genera *Eryon*, *Glyphea*, etc., and Cirripeds of the genus *Pollicipes*, here first found. (*b.*) *Insects.*—Coleopters, gen. *Elater*, *Melolontha*, *Berosus*, etc.; Neuropters, gen. *Ephemera*, *Libellula*, *Orthophlebia*, etc.; Orthopters, gen. *Gryllus*, etc.; Hemipters, gen. *Cicada*, *Cimicides*, etc.; Dipters, gen. *Asilus*, etc.

4. **Vertebrates.**—(*a.*) *Fishes.*—Fig. 707, *Æchmodus* (Tetragonolepis), a restoration of the fish; fig. 707 *a*, scales.

(*b.*) *Reptiles.*—All the Reptiles have biconcave vertebræ. Fig. 708, *Ichthyo-*

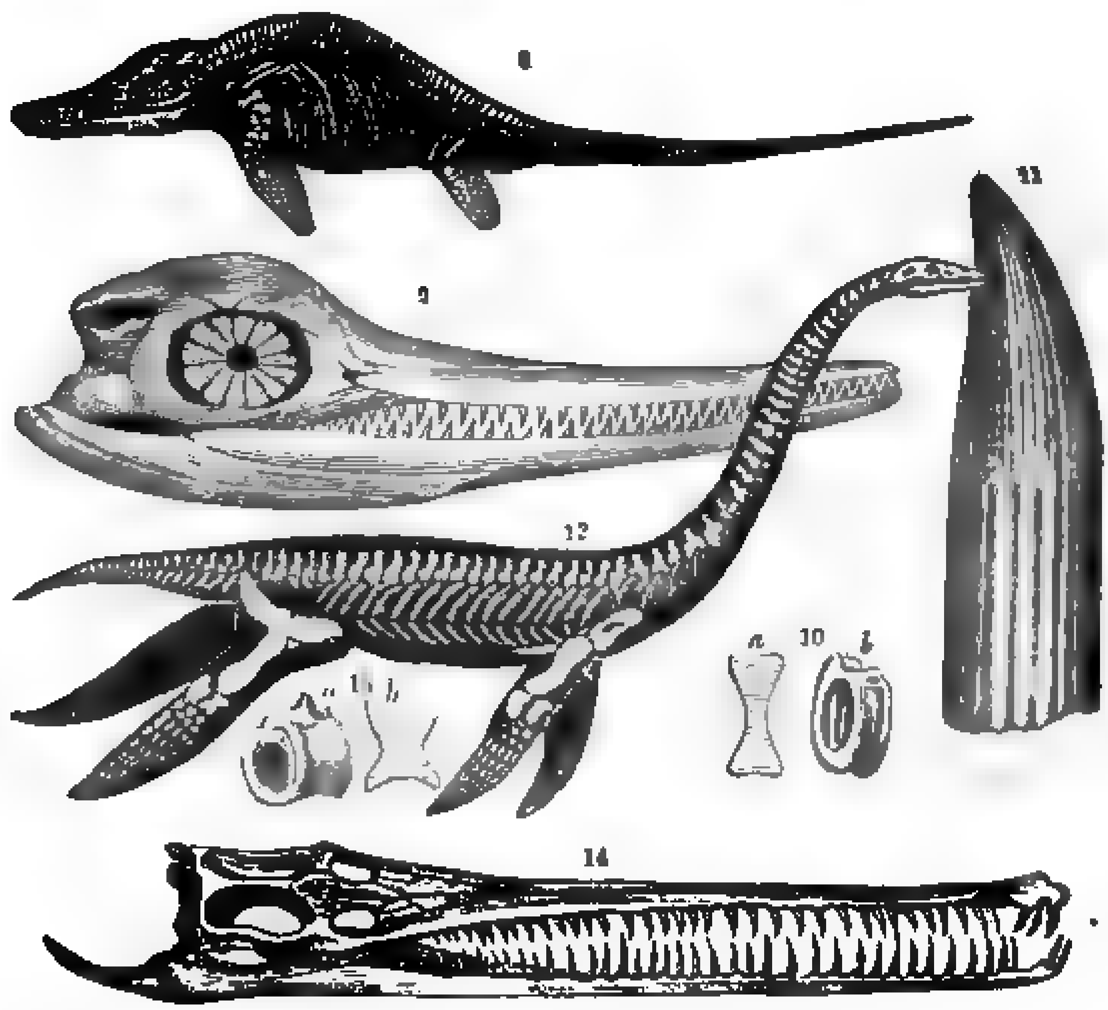
saurus communis; fig. 709, head of same; figs. 710 *a*, 710 *b*, view and section of vertebra; fig. 711, tooth of same, natural size. Fig. 712, *Plesiosaurus dolicho-*

Fig. 707.



GANOID.—Æchmodus (Tetragonolepis) (× ½); a, Scales of same.

Figs. 708–714.



REPTILES.—Fig. 708, Ichthyosaurus communis (× $\frac{1}{100}$); 709, Head of same (× $\frac{1}{20}$); 710 *a*, 710 *b*, view and section of vertebra of same (× ½); 711, Tooth of same, natural size; 712, Plesiosaurus dolichodeirus (× $\frac{1}{30}$); 713 *a*, 713 *b*, view and section of vertebra of same; 714, Mystriosaurus Tiedmanni.

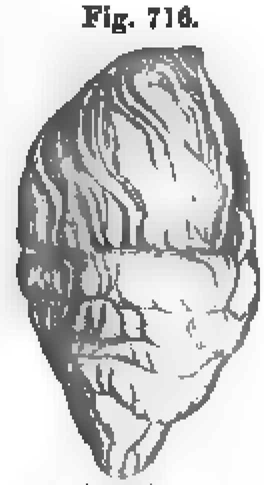
deirus; figs. 713 *a*, 713 *b*, view and section of vertebra. Fig. 715, *P. macrocephalus.* Fig. 714, *Mystriosaurus* (Teleosaurus) *Tiedmanni*, of the Crocodilian order.

Fig. 715.

REPTILE.—Plesiosaurus macrocephalus (× $\frac{1}{40}$).

Other Lias genera of Crocodilians of the Teleosaur family were the *Macrospondylus* and *Pelagosaurus*, specimens of which are found in Wurtemberg. Fig. 716 is a coprolite of a Saurian.

Fig. 716.



Coprolite.

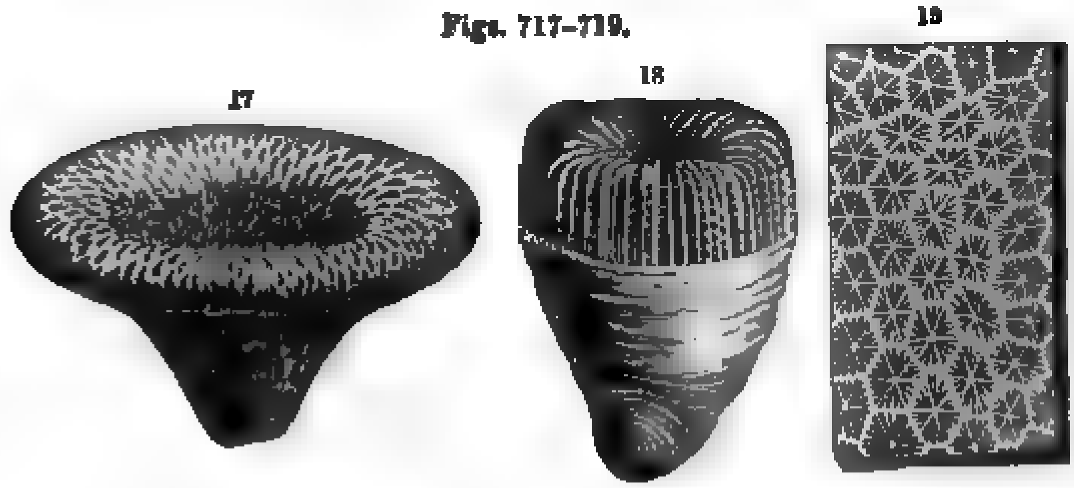
2. Oolitic Epoch.

1. Plants.—The following are some of the common genera: of Ferns, *Pecopteris, Tæniopteris, Sagenopteris, Glossopteris;* of Cycads, *Pterophyllum, Zamites, Palæozamia, Mantellia* (or Cycadeoidea); of Conifers, *Taxites, Thuyites, Dammarites.* There are also species of *Equisetum.* Fig. 671, Portland "dirt-bed," with stumps of trees; fig. 673, *Mantellia megalophylla*, from the "dirt bed."

2. Protozoans.—*Sponges.*—Sponges are common, and are of many species. Fig. 717, *Scyphia reticulata*, from the Oxford Oolite.

3. **Radiates.**—(*a.*) *Corals.*—Fig. 718, *Montlivaltia caryophyllata*, from the Bath Oolite; fig. 719, *Prionastrea oblonga*, Lower Oolite. *Anabacia Orbulites* is a disk-shape coral of the Fungia family, from the Lower and Middle Oolite.

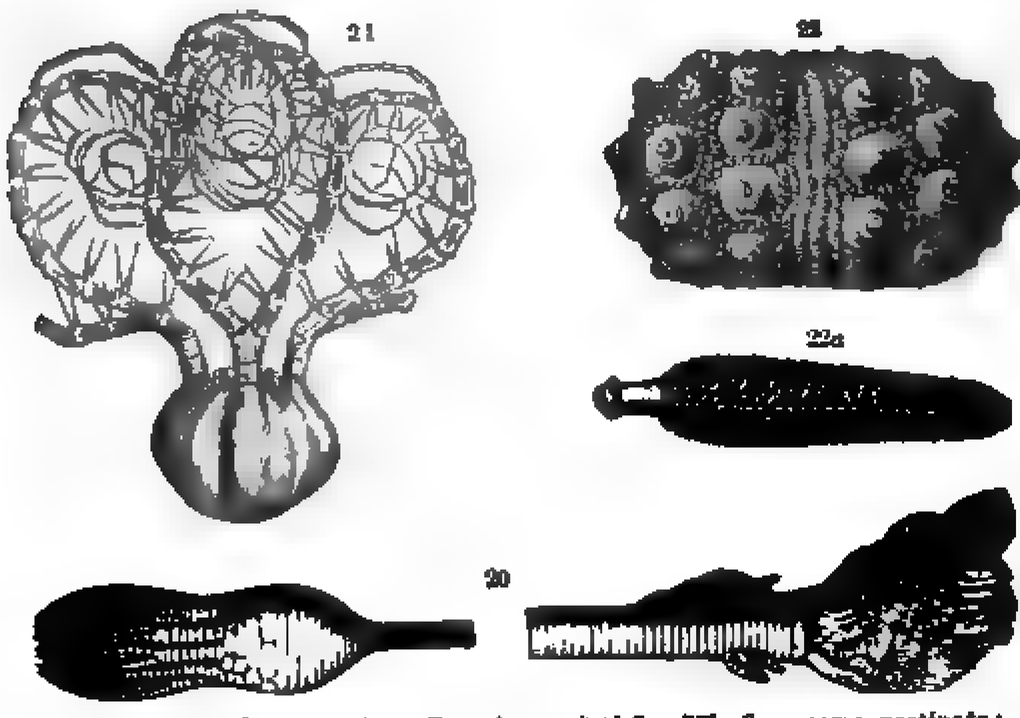
Figs. 717–719.



SPONGE.—Fig. 717, Scyphia reticulata. POLYP-CORALS.—Fig. 718, Montlivaltia caryophyllata; 719, Prionastrea oblonga.

(*b.*) *Echinoderms.*—Fig. 720, *Apiocrinus Roysianus*, from the Coral limestone,—only the top and lower part of the stem given. Fig. 721, *Saccocoma pectinata*,

Figs. 720–722.

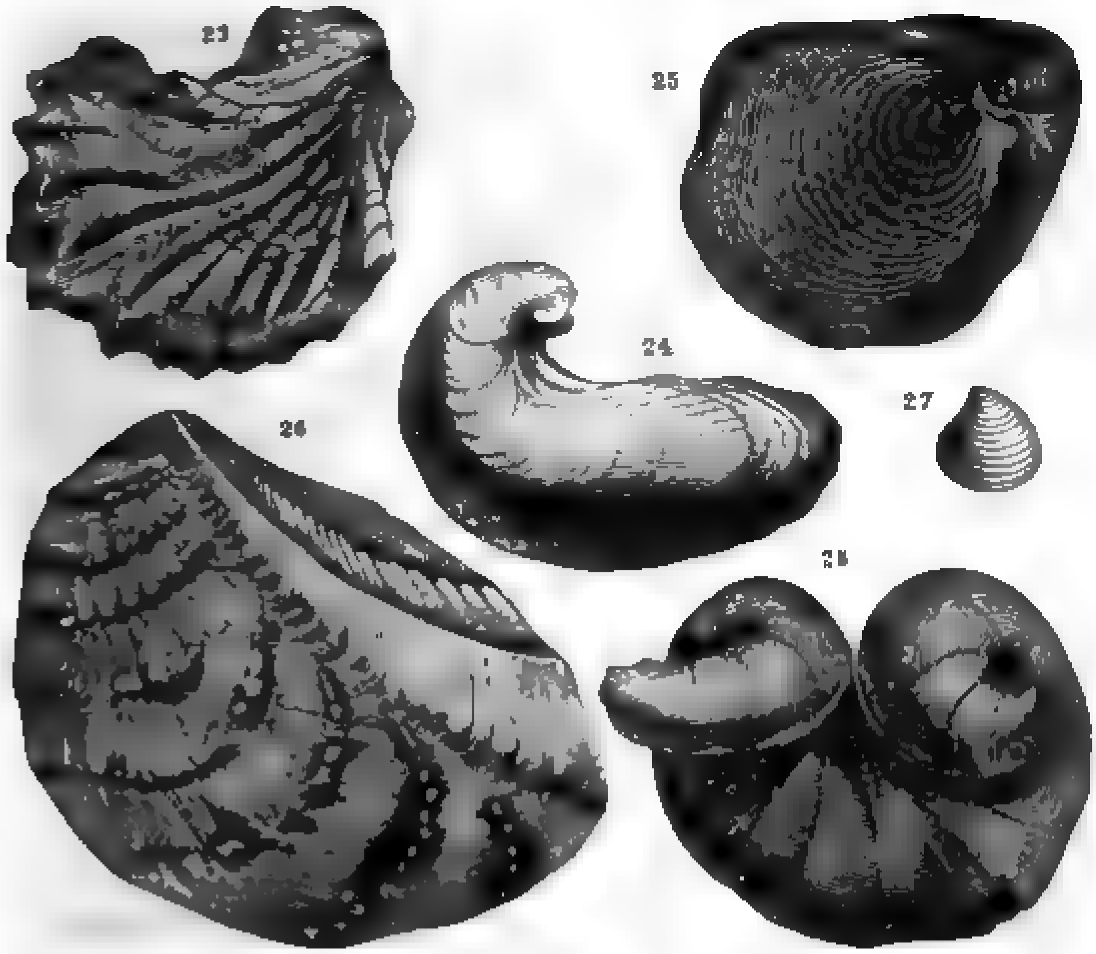


ECHINODERMS.—Fig. 720, Apiocrinus Roysianus (×¼); 721, Saccocoma pectinata; 722, 722 *a*, Cidaris Blumenbachii.

Star-fish related to *Comatula*, from the Middle Oolite; fig. 722, *Cidaris Blumenbachii*; fig. 722 *a*, spine of same.

4. **Mollusks.**—(*a.*) *Conchifers.*—Fig. 723, *Ostrea Marshii*, characteristic of the Oxford (Kelloway) Clay; fig. 724, *Exogyra Virgula*, from the Upper Oolite

Figs. 723–728.

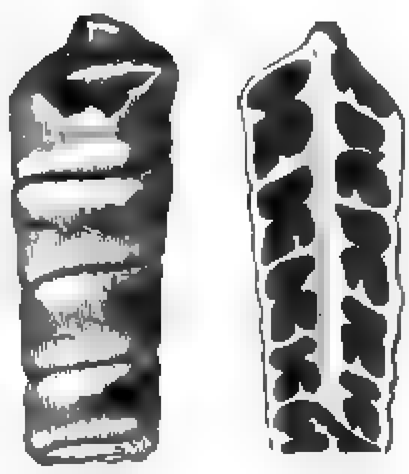


CONCHIFERS.—Fig. 723, Ostrea Marshii; 724, Exogyra Virgula; 725, Gryphæa dilatata; 726, Trigonia clavellata; 727, Astarte minima; 728, Diceras arietina.

(Kimmeridge Clay); fig. 725, *Gryphæa dilatata*; fig. 726, *Trigonia clavellata*, Upper Oolite; fig. 727, *Astarte minima*, Coral limestone; fig. 728, *Diceras arietina*, Coral limestone, a bivalve whose valves are each elongated into the shape of a curved horn,—whence the name, from δις, *twice*, and κερας, *horn*.

(*b.*) *Gasteropods.*—Fig. 729, *Nerinæa Goodhallii*, Coral limestone. The genus is remarkable for the elongated form of the shells, and for having one or more prominent ribs on the inner surface, partly filling or contracting the interior. The appearance of the aperture in one species is shown in fig. 785: the species are confined to the Jurassic and Cretaceous periods. *Purpuroidea nodulata*, from Middle Oolite, *Pleurotomaria*

Fig. 729.



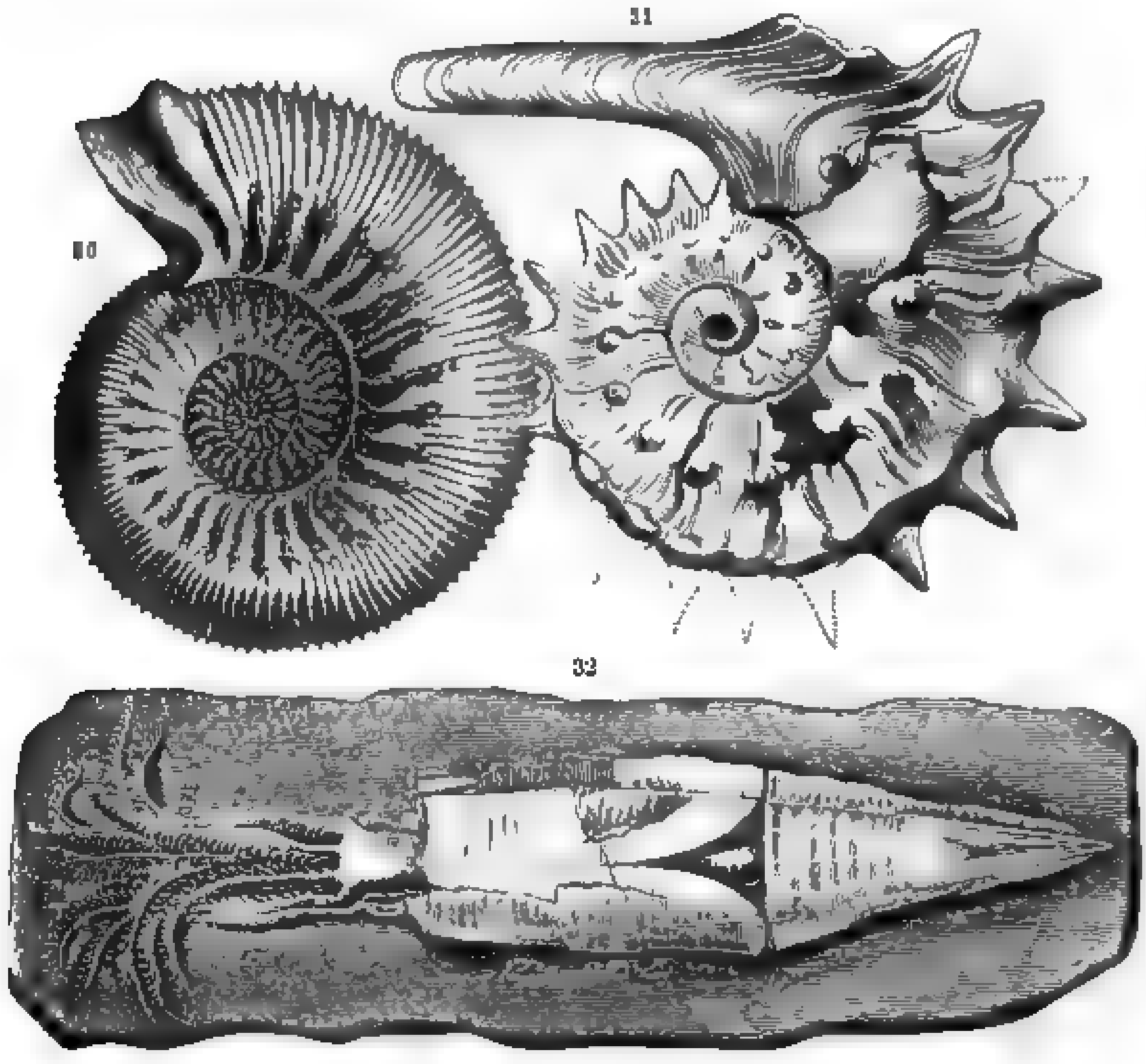
Nerinæa Goodhallii.

ornata, Lower Oolite, are characteristic forms. The Gasteropods with an entire aperture are still far the most abundant species; but a few genera with a beak exist, and the *Purpuroidea* (near the modern Purpura) is one example. Except in the great predominance of species with the aperture entire, the *Gasteropods* have generally a modern aspect: among them there are the genera *Bulla, Pterocera, Cerithium, Fusus, Nerita, Patella?*, and others.

(c.) *Cephalopods.—Tetrabranchs.*—Fig. 730, *Ammonites Humphreysianus*, Lower Oolite; *A. striatulus*, Lower Oolite; *A. cordatus*, Middle Oolite; fig. 731, *A. Jason* Middle Oolite; *A. refractus*, Middle Oolite; also species of *Ancyloceras* and *Toxoceras* (see figs. 787, 789).

Dibranchs.—Belemnites hastatus, Oxford Clay. Fig. 732, *Acanthoteuthis antiquus*, Oxford Clay. Also species of the *Calamary* and *Sepia* families, as *Coccoteuthis* of the latter. The osselet in the Sepia group is calcareous instead of membranous (p. 156).

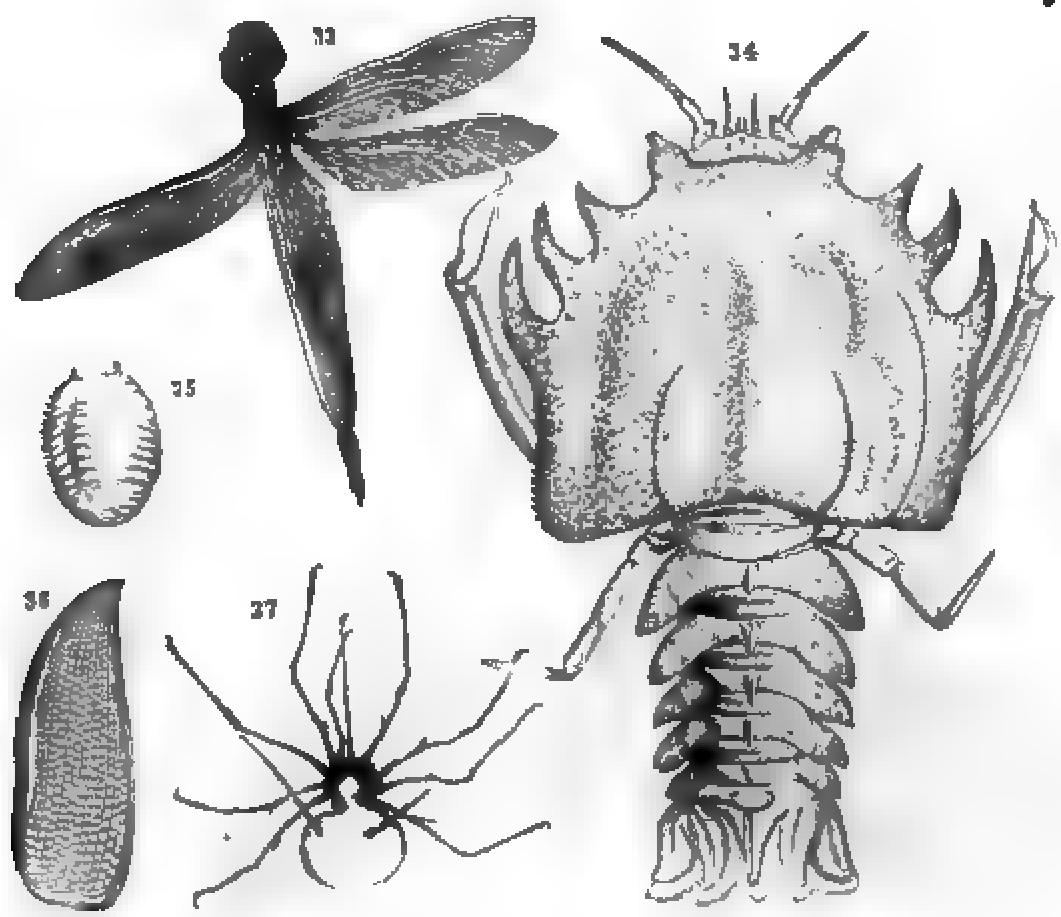
Figs. 730–732.



CEPHALOPODS.—Fig. 730, Ammonites Humphreysianus; 731, A. Jason; 732, Acanthoteuthis antiquus (×½).

5. **Articulates.**—(*a.*) *Crustaceans.*—Fig. 734, *Eryon arctiformis*, Solenhofen. Fig. 735, *Archæoniscus Brodiei*, an Isopod from the Purbeck.

Figs. 733–737.



ARTICULATES.—Fig. 733, Libellula; 734, Eryon arctiformis; 735, Archæoniscus Brodiei; 736, Elytron or wing-case of Buprestis; 737, Palpipes priscus.

(*b.*) *Insects.*—Coleoptera, genera *Carabus*, *Buprestis*, *Coccinella*, etc.; Neuroptera, *Libellula*, *Termes*, etc.; Orthoptera, *Blatta*, *Acheta*, etc.; Hemiptera, *Cicada*, etc.; Diptera, *Culex*, *Chironomus*, *Musca*, etc.; Lepidoptera, *Tineites*, *Sphinx*; Hymenoptera, *Apiaria*. Fig. 733, *Libellula*, Solenhofen. Fig. 736, *Buprestis*, Stonesfield.

(*c.*) *Spiders.*—Fig. 737, *Palpipes priscus*.

Fig. 738.

GANOID.—Aspidorhynchus ($\times \frac{1}{6}$).

6. **Vertebrates.**—(*a.*) *Fishes.*—Fig. 738, *Aspidorhynchus*, Solenhofen. Pycnodont Ganoids (see p. 280) occur among the fossils, and one of large size

from the Upper Oolite is called the *Pycnodus gigas*. Also Selachians, of the genera *Notidanus, Hybodus, Acrodus*.

(*b.*) *Reptiles.*—Fig. 739, *Pterodactylus crassirostris*, from Solenhofen. Fig. 740, section of the tooth of the Dinosaur *Megalosaurus Bucklandi*, Stonesfield. Other Reptiles of the Oolite were the Crocodilians with biconcave vertebræ, *Teleosaurus* (20 feet), *Steneosaurus*; with convexo-concave vertebræ, *Cetiosaurus* (60 feet), etc.; the Lacertians, *Geosaurus* (12 to 13 feet long), *Homœosaurus* (6 feet), etc.; Enaliosaurs of the genera *Ichthyosaurus, Plesiosaurus, Pliosaurus*. Besides these, there were the earliest Chelonian remains (for only tracks of

Figs. 739, 740.

39 40

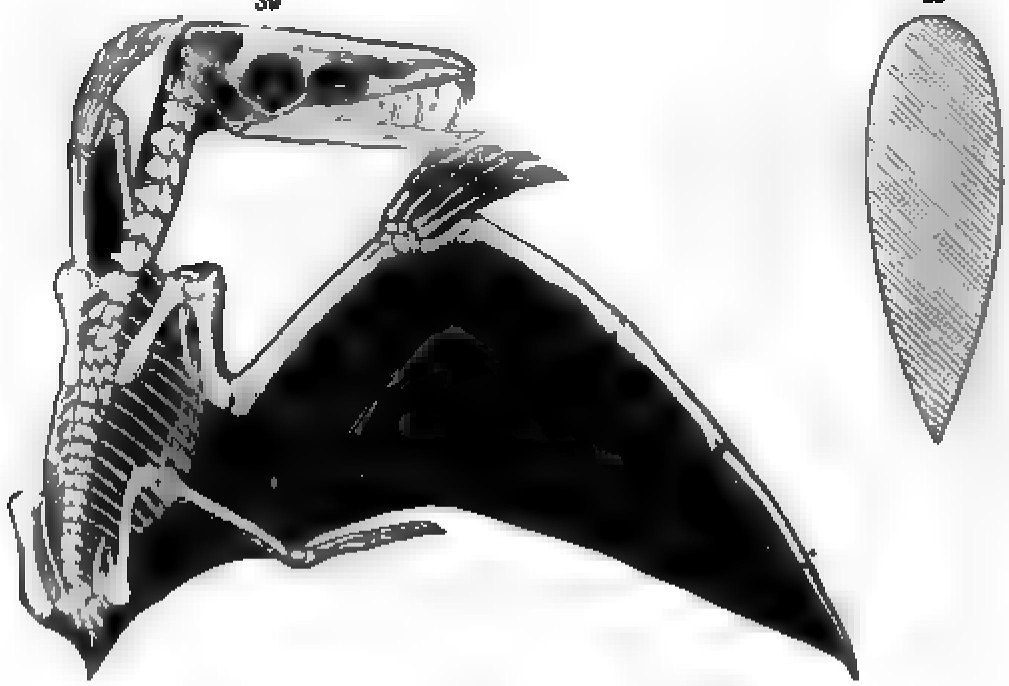


Fig. 739, Pterodactylus crassirostris ($\times \frac{1}{4}$). 740, Section of a tooth of Megalosaurus Bucklandi

uncertain character occur in the Triassic). The species *Idiochelys Wagneri* (six inches long) and *Eurysternum Wagleri* are Turtles from Solenhofen; and *Chelone planiceps* is from the Portland Stone.

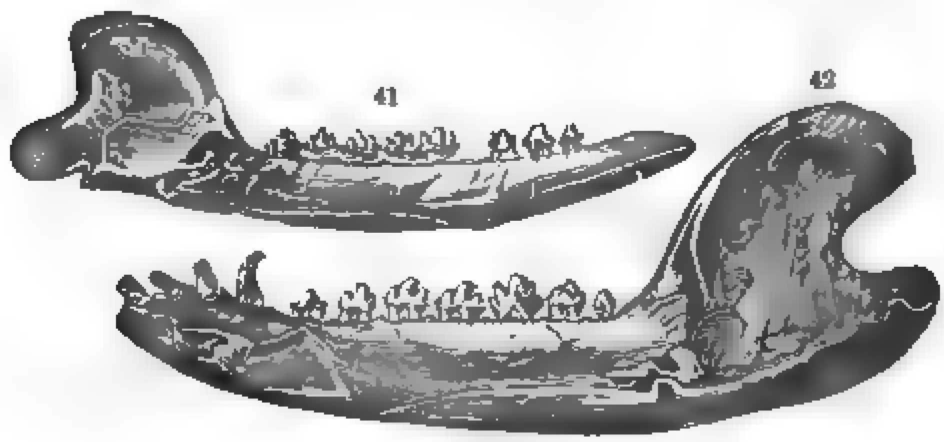
(*c.*) *Birds.*—None.

(*d.*) *Mammals.*—Fig. 741, *Amphitherium* (Thylacotherium) *Broderipii*, twice natural size, Lower Oolite, Stonesfield. Fig. 742, *Phascolotherium*, twice natural size, Stonesfield. *Stereognathus* is the name of another small Stonesfield species, which Owen suggests may have been an herbivorous mammal. On this point he says:—"Admitting the herbivority of the fossil, it is not certain that it was hoofed; there is nothing in the form and structure of the tooth to prove that. Both form and structure are compatible with the hoofless muticate type of herbivorous Mammals, as shown by the Manatee; it is the small size of the *Stereognathus* which renders it less probable that it was a diminutive kind of Manatee, and more probable that it was a diminutive form of Ungulate. But, seeing the manifold diversities of the multi-cuspid form of molar teeth in recent and ex-

that insectivorous unguiculate quadrupeds, it is not impossible but that the *Stereognathus* may have belonged to that order."

Of the species found in the uppermost Oolite, the Purbeck beds, there are the following:—*Triconodon mordax* Owen, nearly as large as a hedgehog (length of ramus of jaw, 1½ inch); another species of the genus, a third larger: they

Figs. 741, 742.



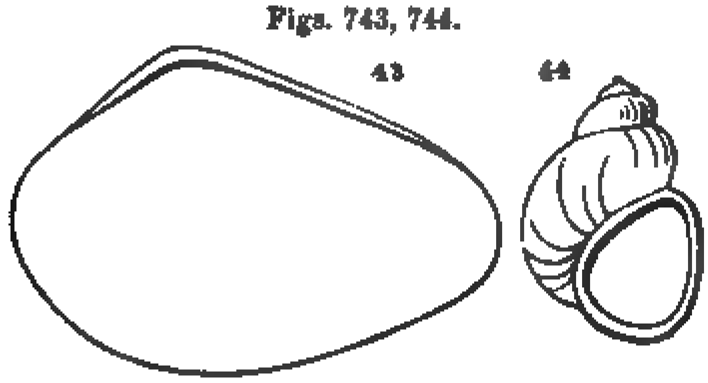
MAMMALS.—Fig. 741, Amphitherium (Thylacotherium) Broderipii (× 2); 742, Phascolotherium Bucklandi (× 2).

are allied to the Stonesfield species, and were probably marsupial. *Plagiaulax Becklesii* and *P. minor* of Falconer,—probably Carnivorous Marsupials; the former as large as an English squirrel (length of ramus of jaw, 1¼ inch), the latter more than half smaller. *Spalacotherium tricuspidens* Owen,—probably an insectivorous Marsupial; length of ramus of lower jaw, about an inch. Another species is the *Ericulus* of Falconer, regarded by him as an Insectivore *not* marsupial.

3. *Wealden Epoch.*

1. **Plants.**—Conifers closely allied to *Araucaria, Abies, Cupressus, Juniperus;* Cycads; trees allied to *Dracæna, Yucca,* and *Bromelia; Equiseta* and *Ferns;* the delicate *Charæ* of rivulets.

Figs. 743, 744.



MOLLUSKS.—Fig. 743, Unio Valdensis; 744, Vivipara (Paludina) Fluviorum.

2. **Mollusks.**—Fresh-water species in large numbers, especially of the

genera *Cyrena*, *Planorbis*, *Limnæa*, *Unio*, and *Paludina*. Fig. 743, *Unio Valdensis*; 744, *Vivipara* (*Paludina*) *Fluviorum*.

3. **Articulates.**—Ostracoids, related to *Cypris*, etc., very abundant in some layers. Insects of thirty or forty families, including Coleopters, Orthopters, Neuropters, Hemipters, and Dipters, or Beetles, Crickets, Dragon-flies, Cicadæ, May-flies, etc.

4. **Vertebrates.**—*Fishes* of the orders of *Ganoids* and *Selachians*, in all thirty or forty species. *Reptiles.*—Enaliosaurs of the genera *Ichthyosaur* and *Plesiosaur*; Dinosaurs of the genera *Iguanodon*, *Hylæosaur*, *Megalosaur*, *Regnosaur*; fig. 745, tooth of the *Iguanodon*; Crocodilians with *biconcave* vertebræ of the genera *Suchosaur*, *Goniopholis*, *Pœcilopleuron*, etc., with *convexo-concave* vertebræ of the genus *Cetiosaur*, but *none* of the modern or procœlian type (*concavo-convex*), which appear first in the Cretaceous; Pterodactyls; Turtles, as the *Tretosternum punctatum* Owen (Trionyx Bakewelli *Mantell*), etc.

Fig. 745.

Iguanodon Mantelli.

Fossils characteristic of the Subdivisions of the Jurassic.

1. LOWER LIAS.—*Diadema seriale* (fig. 694); *Spiriferina Walcotti* (fig. 697); *Gryphæa arcuata* (fig. 699); *Cardinia concinna*; *Pleurotomaria Anglica*; *Ammonites bisulcatus* (or *Bucklandi*) (fig. 701), *A. catenatus*, *A. Conybeari*, *A. Nodotianus* (fig. 700); *Belemnites acutus*.

2. MIDDLE LIAS.—*Pentacrinus Briareus*; *Terebratula rimosa*, *T. numismali* *Gryphæa Cymbium*, *Pecten æquivalvis*, *Pleurotomaria expansa*, *Ammonites marg ritatus*, *A. spinatus*, *Belemnites niger*, *B. paxillosus* (fig. 704).

3. UPPER LIAS.—*Pentacrinus vulgaris*; *Leptæna Moorei*, etc.; *Ostrea Knorr* *Posidonia Bronnii*, *Ctenoides* (Plagiostoma) *gigantea*, *Turbo subplicatus*; *A monites bifrons*, *A. heterophyllus*, *A. radians* (Rein.), *A. serpentinus*, *A. Brai ridgii*, *Belemnites irregularis*.

4. LOWER OOLITE.—(1.) *Inferior Oolite.*—*Dysaster ringens*, *Clypeus H* *Terebratula spinosa*, *T. fimbria*, *T. perovalis*, *Rhynchonella spinosa*; *C* *Marshii*, *O. acuminata*, *Pecten Lens*, *Ctenoides gigantea*, *Trigonia costata*, *I domya Fidicula*; *Turbo gibbosus*, *Pleurotomaria granulata*; *Ammonites Hum* *'sianus* (fig. 730), *A. striatulus*, *A. Braikenridgii*, *Nautilus lineatus*, *Bel* *giganteus*.

(2.) *Great Oolite* (Bath Oolite, including Stonesfield slate, Cornbrash and Marble).—*Apiocrinus rotundus*, *A. Parkinsoni*, *A. elegans*, *Clypeus* . *Terebratula digona*, *Ostrea acuminata*, *Pecten Lens*, *Pholadomya gibbosa*, *costata*; *Purpuroidea nodulata*, *Cylindrites acutus*; *Ammonites Discus*, *A* *A. Braikenridgii*, *Belemnites giganteus*; *Megalosaurus Bucklandi*, *Tele tiosaur*, *Pterodactyls*, etc.

5. MIDDLE OOLITE.—(1.) *Oxford Clay* and *Kelloway Rock.*—*Dysas*

culatus, D. ovalis; Terebratula diphya, T. varians, Ostrea Marshii (fig. 723), *O. gregaria, Gryphæa dilatata, Trigonia elongata, Astarte ovata; Ammonites Jason, A. coronatus, A. Calloviensis, Belemnites hastatus.*

(2.) *Coral Limestone* (Coral Rag).—*Apiocrinus Royssianus, Hemicidaris crenularis, Cidaris coronata, Pygaster patelliformis; Ostrea gregaria, Trigonia Bronnii, T. costata, Diceras arietina* (fig. 728), *Astarte elegans, A. minima* (fig. 727); *Pleurotomaria granulata, Nerinæa fasciata, N. Goodhallii; Ammonites Altenensis, A. plicatilis.* At Solenhofen, *Pterodactylus crassirostris* (fig. 739), and other species.

6. Upper Oolite.—(1.) *Kimmeridge Clay.—Ostrea deltoidea, Exogyra Virgula* (fig. 724), *Trigonia muricata, T. clavellata* (fig. 726), *Cardium striatulum; Nerinæa Goseæ; Ammonites decipiens, A. rotundus, A. biplex.*

(2.) *Portland Stone.—Ostrea expansa, Trigonia gibbosa, T. elongata, T. clavellata* (fig. 726), *Lucina Portlandica, Cardium dissimile, Mactra rostrata; Natica elegans; Ammonites biplex, A. giganteus.*

7. Purbeck Beds.—*Hemicidaris Purbeckensis; Ostrea distorta, Paludina carinifera; Cypris* (various species); *Mantellia megalophylla.*

III. General Observations.

American Geography.—From the outcropping of the Jurassic beds along the Black Hills and the flanks of the Rocky Mountains, Hayden & Meek have inferred with good reason that these rocks probably underlie the wide-spread Cretaceous strata of the eastern slope of the Rocky Mountains; and, as the elevation of the Rocky chain above the ocean was not completed until long after the close of the Cretaceous period (although it may have been begun before it), we may infer that the condition mentioned as characteristic of the Triassic period—a shallow submergence beneath an inland sea (p. 442)—was followed in the Jurassic period by a somewhat deeper submergence, or at least that the waters communicated directly with the ocean, so that marine life once more covered the Rocky Mountain region from Kansas westward beyond the summit of the chain, and in these shallow seas limestones were forming again, as in the latter half of the Carboniferous age.

The absence of sea-shore Jurassic beds from the Atlantic border leads to the same conclusions with regard to the coast in the Jurassic period that were deduced for the Triassic (p. 442).

European Geography.—The Jurassic period commenced in England with the marine deposits of the Lias. Through the Oolite the alternations were very numerous, indicating oscillations between clear seas and shallow water or half-emerging land, in the course of which there were coral reefs in England and Europe. The evidences of shallow water and emerging flats increase to-

wards the close of the period, dry-land intervals begin to predominate over the marine, and some parts of the Jurassic lands are regions of lakes and estuaries, of forests, and of abundant Reptile life. The history in Europe in part runs parallel with this, although with many local peculiarities.

The position of the Jurassic beds across England on the east of the older parts of the island, and their continuation over parts of northern France, correspond with the view that they were formed on the borders of a German Ocean basin. This is well shown as relates to England on the map on p. 354. Whether there was then a British Channel or not is not yet decided. Some English geologists make the channel of Post-tertiary origin.

Life.—It is evident from the review that, while Conifers and Cycads made up the bulk of the Jurassic forests,—Cestraciont and other Sharks, Rays and Ganoids, the fishes of the world,—Trigoniæ, Gryphææ, Ammonites, and Belemnites, a characteristic part of the Mollusks,—at the same time grazing and carnivorous Dinosaurs and Crocodilians, huge Swimming Saurians, Flying Lizards, and Turtles, existed in vast numbers, and were the dominant inhabitants of the globe. Reptiles were pre-eminent in each of the three elements,—in place of whales in the *water*, of beasts of prey and herbivores on the *land*, and of birds in the *air*. It was the meridian of the Reptile world. And the abundance and variety of the remains in Britain seem to point to that region as one of the most populous centres in the Reptile world.

Along with these powerful Reptiles, there were small Marsupials, and probably Insectivores,—announcements of the decline of the Reptile Age, and precursors of the reign of Mammals.

The great multitudes of Reptile and other remains entombed in the Stonesfield slate, the Wealden, and the beds at Solenhofen, do not indicate an excess of population about these spots. They point out only the places where the conditions were favorable for the preservation of such relics, and prove that the land was covered with foliage and swarming with life, everywhere, we may believe, as regards Insects, and at least in the vicinity of water for Reptiles. A bed of coal is not proof of more vegetation than elsewhere, but of the presence of fresh waters during the accumulation and afterwards, which favored the kind of decomposition required for making coal (see p. 361).

The dirt-bed of Portland, abounding in Mammalian remains, and yet only five inches thick, shows strikingly what we should find in the Coal formation, with its many scores of dirt-beds of far greater thickness, if Mammals were then living.

Climate.—The existence of *Belemnites paxillosus* and *Ammonites biplex* (or closely-allied species) in the Arctic, the Andes of South America, and Europe, indicates a remarkable uniformity of climate over the globe in the Jurassic period. No facts connected with the geographical distribution of species are yet ascertained that sustain the idea of a diversity of zones approaching the present. The facts favor the view that the climate of the Arctic in the Jurassic period was at least warm-temperate.

CRETACEOUS PERIOD (18).

The Cretaceous period is the closing era of the Reptilian Age. It is remarkable for the number of genera of Mollusks and Reptiles which end with it, and also for the appearance, during its progress, of the modern types of plants and fishes.

The name Cretaceous is from the Latin *creta*, chalk. The Chalk of England and Europe is one of the rocks of the period.

1. AMERICAN.

Epochs.—1. Epoch of the Earlier Cretaceous· 2. Epoch of the Later Cretaceous.

It is probable that only the later half of the Cretaceous period of Europe is represented by these epochs in America.

I. Rocks: kinds and distribution.

The Cretaceous beds occur (1) at intervals along the *Atlantic border* south of New York, from New Jersey to South Carolina, (2) extensively over the States along the *Gulf border*, and (3) through a large part of the *Western Interior region*, over the slopes of the Rocky Mountains, from Texas northward, to the head-waters of the Missouri on the east of the summit of the chain, and far into the Colorado region on the west. Still farther northwest in British America, they appear on the Saskatchewan and Assiniboine, and also on the Arctic Sea, near the mouth of the Mackenzie. North of New York on the Atlantic border they are unknown.

On the map, p. 133, the Cretaceous areas are indicated by broken lines running obliquely from the right above to the left below: one area crosses New Jersey (the other outcrops on the Atlantic border are too small to be indicated); a far more extensive area covers the Gulf States, and another, the region west of the Mississippi. The region along the Gulf border as well as Atlantic,

lined closely from the left to the right, is Tertiary; and it probably covers Cretaceous throughout. The part of the Rocky Mountain region more openly lined in the same direction has a surface of fresh-water Tertiary; but Cretaceous beds, in many places at least, lie beneath.

The rocks comprise beds of sand, marl, clay, loosely-aggregated shell limestone and compact limestone; they include in North America *no chalk*.

The sandy layers predominate. They are of various colors,—white, gray, reddish, dark green; and, though sometimes solid, they are often so loose that they may be rubbed to pieces in the hand, or worked out by a pick and shovel. Layers of potter's clay occur in the series.

The dark-green sandy variety constitutes extensive layers, and goes by the name of *Green-sand;* and, as it is valuable for fertilizing purposes and is extensively dug for this object, it is called *Marl* in New Jersey and elsewhere. This Green-sand owes its peculiarities to a green silicate of iron and potash, which forms the bulk of it, and sometimes even 90 per cent., the rest being ordinary sand mixed with it. There is a trace of phosphate of lime, evidently derived from animal remains,—as animal membranes and shells contain a small percentage of phosphates. It is supposed to owe its value in agriculture to the potash and the phosphates. Fossil shells are very abundant in many of the arenaceous and marly beds, and in some they lie packed together in great numbers, as if the sweepings of a beach, or the accumulations of a growing bed in shallow waters, sometimes cemented together, but generally loose, so as to be easily picked out by the fingers.

The Cretaceous limestones in Texas are firm and compact, and some beds contain chert distributed through them, as the flint through the Chalk of England.

The Cretaceous formation has a thickness in New Jersey of 400 to 500 feet; in Alabama, of 500 to 600; in Texas, of about 800; and in the region of the Upper Missouri, of 2000 to 2500 feet.

The two epochs, that of the *Earlier* and that of the *Later* Cretaceous, are represented in the Western Interior region (including Texas); while on the Atlantic and Gulf borders, in New Jersey, and elsewhere, the beds, exclusive perhaps of the lowest unfossiliferous layers, belong to the *Later* Cretaceous.

The interior limit of the Cretaceous formation (see map, p. 133) follows a line across New Jersey from Staten Island to the head of Delaware Bay; across Delaware to the Chesapeake; across Maryland between Annapolis and Baltimore, southwest into Virginia; occurs at Elizabeth on Cape Fear River in

North Carolina, and sparingly in South Carolina. But more to the westward, at Macon, Georgia, commences the large Southern Cretaceous region, which is continued into the Mississippi basin, and whose inner outline passes by Columbus in Georgia, Montgomery in Alabama, and then bends northward over northwestern Mississippi towards the mouth of the Ohio; it descends southward again on the west side of the Mississippi over eastern Arkansas, spreading at the same time westward south of Little Rock and Fort Washita; not far from the last point the Cretaceous area expands southward over part of Texas, and northward over a large part of the eastern slope of the Rocky Mountains, as already mentioned. About the summits of the Rocky Mountains, Cretaceous beds occur in New Mexico along the Rio Grande del Norte to its head-waters; and west of the summit they spread over the region of the Colorado as far as the meridian of 113° W.

On the Pacific coast, Cretaceous rocks have been found on the east side of Vancouver's Island, and on some neighboring islands; also, according to Whitney, at various points in the Coast Range in California and along the foot-hills of the Sierra Nevada, from Placer county to Shasta; they contain beds of coal on Vancouver's Island and in California; part of the California rocks are metamorphic.

As the Cretaceous formation is most fully represented in the region of the Upper Missouri, a detailed section of it, by Meek & Hayden, is here given, beginning below:—

1. Earlier Cretaceous.
   1. *Dakota group.*—Yellowish, reddish, and whitish sandstones and clays, with lignite and fossil Angiospermous leaves: thickness, 400 feet. Location, near Dakota, and reaching southward into northeastern Kansas. This division may require to be united with No. 2 (M. & H.).
   2. *Benton group.*—Gray laminated clays, with some limestone: thickness, 800 feet. Location, near Fort Benton, on the Upper Missouri, also below the Great Bend; eastern slope of the Rocky Mountains.
   3. *Niobrara group.*—Grayish calcareous marl: thickness, 200 feet. Location, Bluffs on the Missouri, below the Great Bend, &c.
2. Later Cretaceous.
   4. *Pierre group.*—Plastic clays: thickness, 700 feet;—middle part barren of fossils. Located on the Missouri near Great Bend, about Fort Pierre and out to the Bad Lands, on Sage Creek, Cheyenne River, White River above the Bad Lands.
   5. *Fox Hills group.*—Gray ferruginous and yellowish sandstones and arenaceous clays: thickness, 500 feet. Location, Fox Hills near Moreau River, above Fort Pierre near Long Lake, and along the base of Big Horn Mountains.

In New Jersey, the beds and their relations to those of Nebraska are thus stated by Meek & Hayden from the observations of G. H. Cook:—

1. Earlier Cretaceous ?.—No. 1? Bluish and gray clays, micaceous sand, with fossil wood and Angiospermous leaves: thickness, 130 feet or more.
2. Later Cretaceous.—Nos. 4 and 5. (*a.*) Dark clays (130 feet), overlaid by (*b.*) the *first* bed of *Green-sand*, 50 feet thick.—No. 5. (*a.*) Sand colored by iron, 60 to 70 feet; (*b.*) second bed of *Green-sand*, 45 to 50 feet; (*c.*) yellow limestone.

In Alabama the formation consists of—

1. EARLIER CRETACEOUS?—No. 1?. Dark-blue and mottled shales or clay, with only vegetable remains; 300 feet or more.

2. LATER CRETACEOUS.—No. 4. (*a.*) Grayish and yellowish sand, often obliquely laminated; 15 feet. (*b.*) Gray sand, with fossil shells; 6 feet. (*c.*) Loose white sand, with shells; 45 feet. No. 5. (*a.*) Soft white limestone, with shells; 6 feet. (*b.*) Dark limestone; 4 feet. (Winchell.)

In Texas the beds consist mainly of compact limestone, and the larger part are of the *Later* Cretaceous. Shumard gives the following subdivisions:—Marly clay, 150 feet, overlaid by arenaceous beds, 80 feet (Nos. 1 and 2). (*a.*) Caprotina limestone, containing *Orbitolina Texana*, etc., 55 feet; (*b.*) Blue marl, 50 feet; (*c.*) Washita limestone, 100 to 120 feet (No. 3). (*d.*) Austin limestone, 100 to 120 feet (No. 4). (*e.*) Comanche Peak Group, 300 to 400 feet; (*f.*) Caprina limestone, 60 feet.

Other localities of the rocks of the several subdivisions are as follow:—

No. 1, at different points in New Mexico (Newberry). No. 2, on the north branch of the Saskatchewan, west of Fort à la Corne, lat. 54° N.; in New Mexico (Meek). No. 3, over the region from Kansas through Arkansas to Texas; in the Pyramid Mountain. No. 4, in British America, on the Saskatchewan and Assiniboine; on Vancouver Island; Sucia Islands, in the Gulf of Georgia. No. 5, at Deer Creek, on the North Platte, and not identified south of this. (Meek & Hayden.)

The *Green-sand beds* of New Jersey, it is seen, belong to the Later Cretaceous, while in Europe the earlier and the later Green-sand formations pertain to the *first half* of the Cretaceous period, the part not yet known to be represented in America. These Green-sand beds are, therefore, not confined to a particular epoch, and of late have been found to occur even in the Palæozoic, and to be in progress in existing seas.

The green grains (called also *Glauconite*) consist of about 50 per cent. of silica, 20 to 25 protoxyd of iron, 8 to 12 potash and soda (mostly potash), and 7 to 10 water, with also a trace of phosphate of lime. For analyses, see author's Treatise on Mineralogy.

The glauconite of the Chalk differs from that of the Lower Silurian rocks of Canada (p. 176) in containing no alumina, the latter being a hydrous silicate of alumina and protoxyd of iron, with about 8 per cent. of potash. (Hunt.)

II. Life.

1. *Plants.*

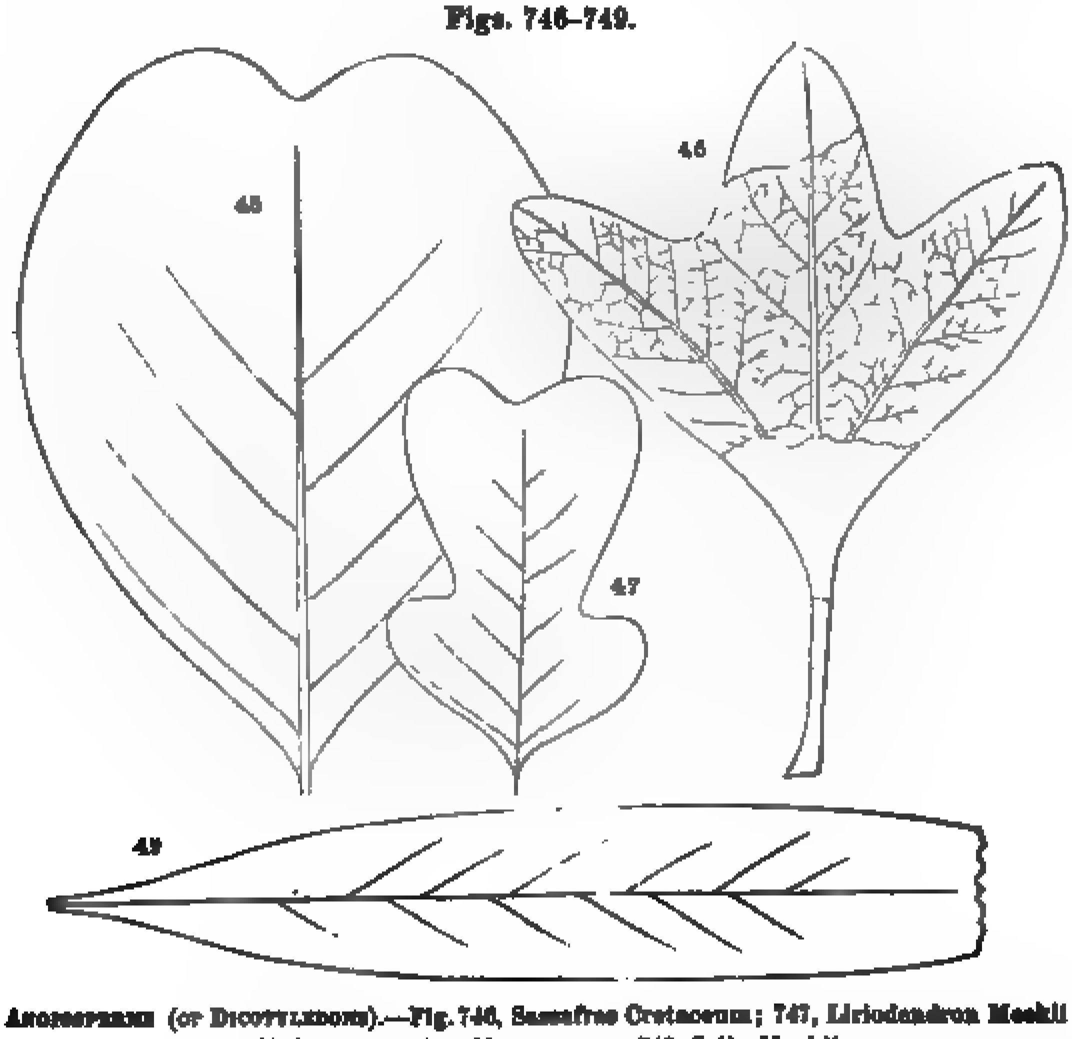
During the Cretaceous period there was a great change in the vegetation of the American continents. The Cycads of the Triassic and Jurassic were accompanied by the *first of the great modern group of Angiosperms*,—the class which includes the Oak, Maple, Willow, and the ordinary fruit-trees of temperate regions,—in fact, all plants that have a bark, excepting the Conifers. More than one hundred species have been collected, and half of them were allied to trees

of our own forests,—the Tulip-tree, Oak, Dogwood, Beech, Poplar, Willow, Alder, Button-wood, and Sassafras, or the genera *Liriodendron* (fig. 747), *Quercus, Cornus, Fagus, Populus, Salix* (fig. 749), *Alnus, Platanus, Sassafras* (fig. 746), *Liquidambar, Taxodium*, etc. These species have been collected in New Jersey, Alabama, Nebraska, Kansas, New Mexico, and Vancouver's Island on the Pacific (Newberry), and mainly from the earliest or Dakota group.

Besides Angiosperms, there were also the *first of the Palms*. It is, however, still questioned whether any American Cretaceous specimens of this tribe have been found. Fossil palm-leaves of the fan-palm kind (genus *Sabal*) are met with on Vancouver's Island, in deposits which have been pronounced to be Cretaceous.

Fig. 746, *Sassafras Cretaceum* Newberry, from the Dakota group, along with the three following (Meek & Hayden): fig. 747, *Liriodendron Meekii*

Figs. 746–749.



ANGIOSPERMS (OF DICOTYLEDONS).—Fig. 746, Sassafras Cretaceum; 747, Liriodendron Meekii; 748, Leguminosites Marcouanus; 749, Salix Meekii.

Heer; fig. 748, *Leguminosites Marcouanus* Heer; fig. 749, *Salix Meekii* Newberry.

Large stumps of Cycads have been found in Maryland near Baltimore; one is 12 inches in diameter and 15 high. (P. T. Tyson, who observes that they may be Upper Jurassic.)

2. *Animals.*

Among Protozoans, the group of Rhizopods has a special importance in the Cretaceous period. They are abundant in many of the beds in New Jersey and other Cretaceous regions of North America, though less so than in the chalk beds of Europe. In one genus, *Orbitolina*, the species are disk-shaped (fig. 750), and closely resemble in form some of the Nummulites of the early Tertiary. Sponges also are a common fossil, although little known thus far in America.

In the sub-kingdom of Mollusks, the more characteristic genera of Conchifers are the three of Oysters, *Ostrea* (fig. 753), *Gryphæa* (figs. 755, 756), and *Exogyra* (fig. 754) (species of which occurred in the Jurassic period, but are more common and larger in the Cretaceous), and *Inoceramus* (fig. 757), a genus related to Avicula and Mytilus, some species of which are of great size and have the surface in undulations. *Exogyra* and *Inoceramus* end with the Cretaceous, and but one *Gryphæa* is known afterward.

Another group characteristic of the Chalk period, and, moreover, not known after it, is that of the *Rudistes* (figs. 782–784). It includes the genera *Hippurites*, *Radiolites*, *Spherulites*, and a few others. *Hippurites* has a long tapering form (fig. 782), somewhat like a nearly straight, but rude, horn with a lid on the top, the lid being the upper valve, and the conical portion the lower. Within there is a subcylindrical, tapering cavity, having one or more projecting ridges on the sides running the whole length. Fig. 782 *a* shows the interior of one: there are two prominent ridges, but one is only partly free in the interior space. The other genera have a similar anomalous character, but differ in the interior. Fig. 783 represents the lid or upper valve of a *Radiolites*, showing the projections below (*b*, *c*) to which the muscles closing the lid are attached; and fig. 784 is the same in *Spherulites*. The Rudistes are supposed to be related to *Chama* among the Dimyary Mollusks.

Of Cephalopods, there are in the Cretaceous beds numerous *Ammonites* and *Belemnites*. Some of the Ammonites from beyond the Mississippi are over three feet in diameter. There is also a multiplication of other genera of the Ammonite family, the shells of which are like Ammonites more or less uncoiled; as *Scaphites* (figs. 766, 767), from *scapha, a boat; Crioceras* (fig. 786), from *κριος, a ram's horn; Ancyloceras* (fig. 787), from *αγκυλη, a hook* or *handle; Hamites,*

(fig. 788), from *hamus, a hook; Toxoceras* (fig. 789), from *τοξον, a bow; Baculites* (fig. 768), from *baculum, a walking-stick. Turrilites* (fig. 790) is another form, unlike other *Ammonitids* in being a turreted spiral. Another genus resembles an opened spiral, and is called *Helicoceras*. Among these genera, only *Ammonites, Scaphites, Ancyloceras, Hamites, Ptychoceras, Baculites, Turrilites*, and *Helicoceras*, have been found in American Cretaceous rocks. *Baculites ovatus* (fig. 768) attains a length of a foot or more, and a diameter of 2½ inches, and *Scaphites Conradi* (fig. 766) a length of six inches. *Ancyloceras* and *Toxoceras* occur first in the European Jurassic.

Among Vertebrates, there is the first appearance of several prominent modern groups, marking grand steps of progress in the life of the world.

1. *Common or Osseous Fishes*, or *Teliosts*,—the tribe which includes nearly all fishes, excepting Ganoids and Sharks, and, consequently, nearly all edible species. Their distinguishing characteristics are mentioned on page 278.

2. *True Crocodiles*, in the class of Reptiles.

3. *Cetaceans* or Whales, in the class of Mammals.

Besides these marks of progress, there are many other new genera of Fishes and Reptiles.

The *Squalodonts*, or modern tribe of Sharks having teeth with sharp cutting edges, besides other peculiarities, are greatly multiplied. The new tribes do not displace the Cestracionts and Ganoids, which continue to be common until the close of the Cretaceous period, and still have some representatives.

Figs. 772, 773, represent some of the Sharks' teeth. Fig. 773 are pavement-teeth of a fish of the old Cestraciont group, pertaining to the genus *Ptychodus*, characteristic of the Cretaceous period.

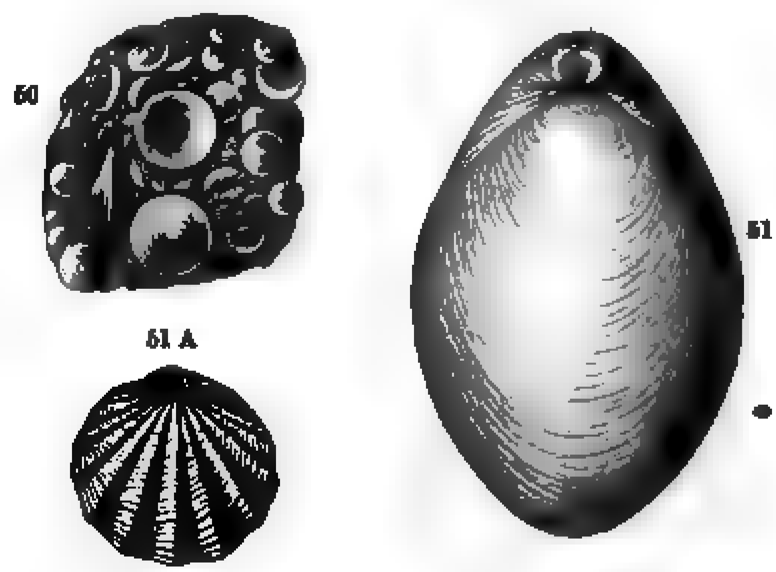
Beyond the Mississippi, remains of Reptiles have been found, and both there and in New Jersey bones of a colossal Lacertian Reptile of the genus *Mosasaurus*. These Reptiles are supposed to have been web-footed and aquatic in habit, while at the same time carnivorous. The tail was flattened, long, and powerful, and thus fitted for sculling through the water. The New Jersey species was 24 feet long. Another large Reptile, *Hadrosaurus Foulkii* Leidy, is related to the Iguanodon of the Wealden, and was probably 25 feet long; its remains were found near Haddonfield, N.J.

Bones of Whales also occur in the New Jersey Cretaceous. They are the earliest species yet discovered of this tribe of Mammals.

Characteristic Species.

1. **Protozoans.**—*Rhizopods.*—*Textilaria Missouriensis*, *T. globulosa*, *Phanerostomum senarium*, *Rotalia lenticulina*, *R. senaria*, *Grammostomum phyllodes*,

Figs. 750, 751 A, B.



RHIZOPODS.—Fig. 750, Orbitolina Texana. BRACHIOPODS.—Fig. 751 A, Terebratulina plicata; 751 B, Terebratula Harlani.

from the Cretaceous of the Upper Missouri, identified by Ehrenberg; *Cristellaria rotulata*, *Dentalina pulchra* Gabb, etc., from New Jersey; fig. 750, *Orbitolina Texana* Roemer, from Texas, a species having the form of a disk, slightly conical.

2. **Radiates.**—(*a.*) *Polyp-Corals.*—*Astrocœnia Sancti-Sabæ* Roemer, Texas; *Montlivaltia Atlantica*, New Jersey, etc.

(*b.*) *Echinoderms.*—*Holaster simplex*; *Ananchytes cinctus*, *Toxaster elegans*; also species of *Diadema*, *Hemiaster*, *Holectypus*, *Cyphosoma*, etc.

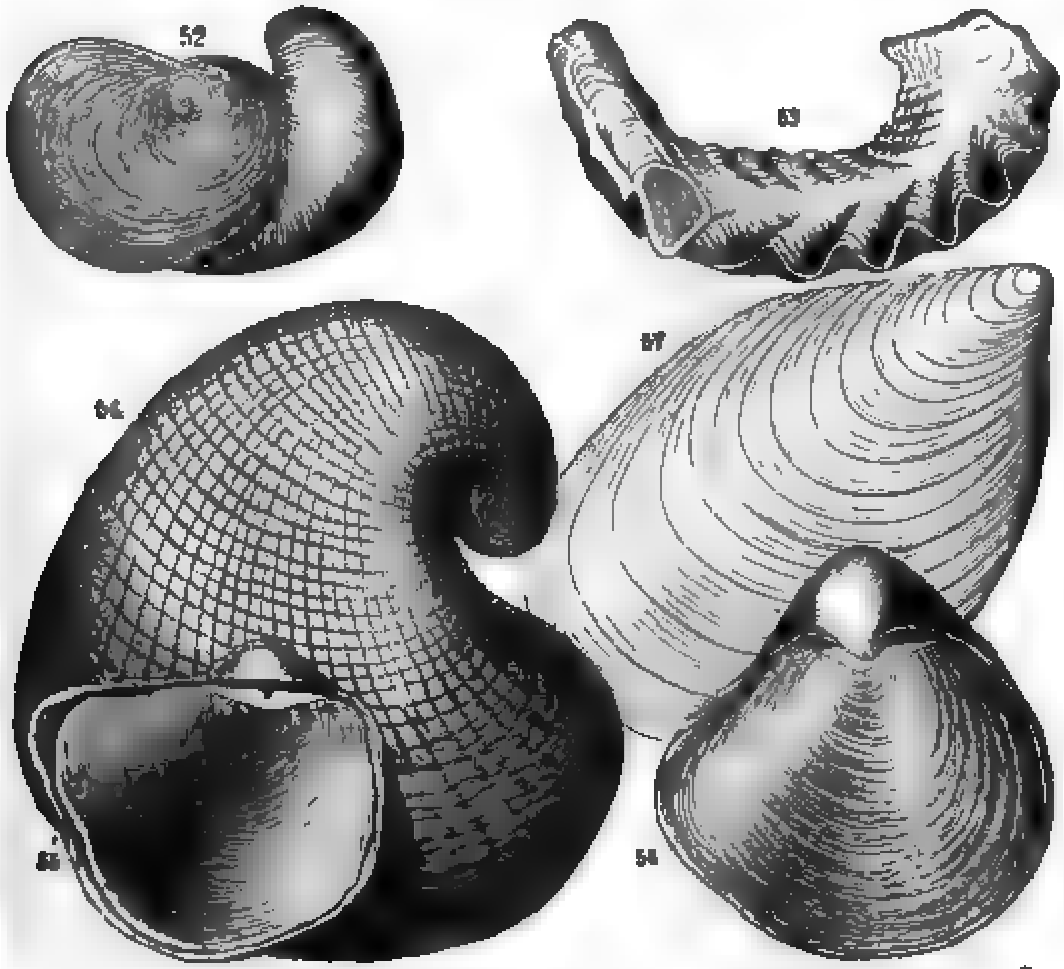
3. **Mollusks.**—(*a.*) *Bryozoans.*—Numerous species have been described and figured by Gabb & Horn, of the genera *Membranipora*, *Flustrella*, *Escharipora*, *Biflustra*, etc.

(*b.*) *Brachiopods.*—Fig. 751 A, *Terebratulina plicata*; fig. 751 B, *Terebratula Harlani* Morton, from New Jersey; *Lingula nitida* M. & H., Nebraska.

(*c.*) *Conchifers.*—Fig. 753, *Ostrea Larva* Lamarck, found also in Europe; *O. congesta* Conrad, from Arkansas and Nebraska; fig. 752, *Exogyra arietina* Roemer, from Texas; fig. 754, *E. costata* Say, from the Cretaceous of the Atlantic and Gulf borders; fig. 755, *Gryphæa vesicularis* Lamk., at nearly all North American localities, and also a European species; fig. 756, *G. Pitcheri* Morton, from Cretaceous region west of the Mississippi River; fig. 757, *Inoceramus problematicus* Schlotheim, from west of the Mississippi, and also a European species. Among Rudistes, *Radiolites Austinensis* Roemer, a species five to six inches in diameter, from Alabama, Mississippi, and Texas; *Radiolites lamellosus*

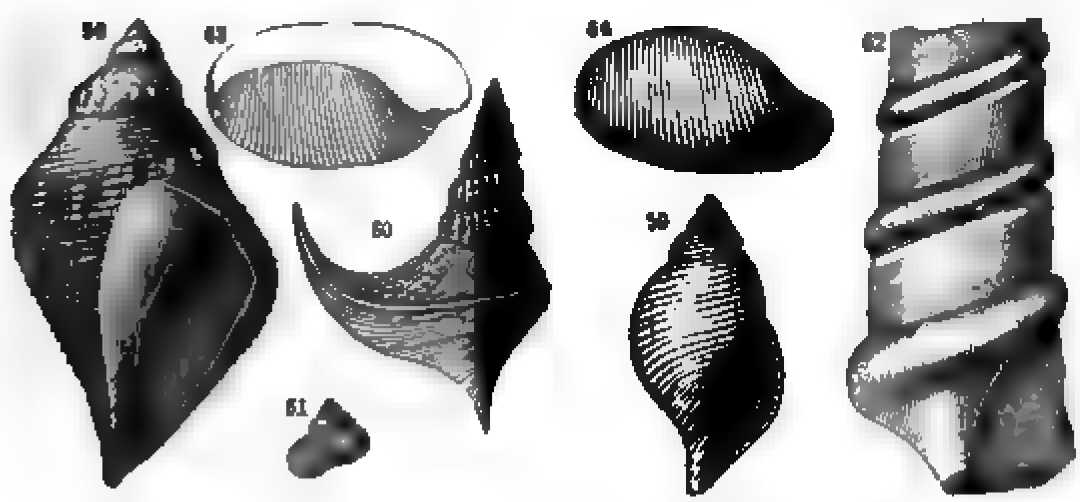
Tuomey, from Alabama; *Hippurites Texanus* Roemer, a species eight inches long and four in diameter, from Texas; *Caprotina Texana* Roemer, from Texas.

Figs. 752–757.



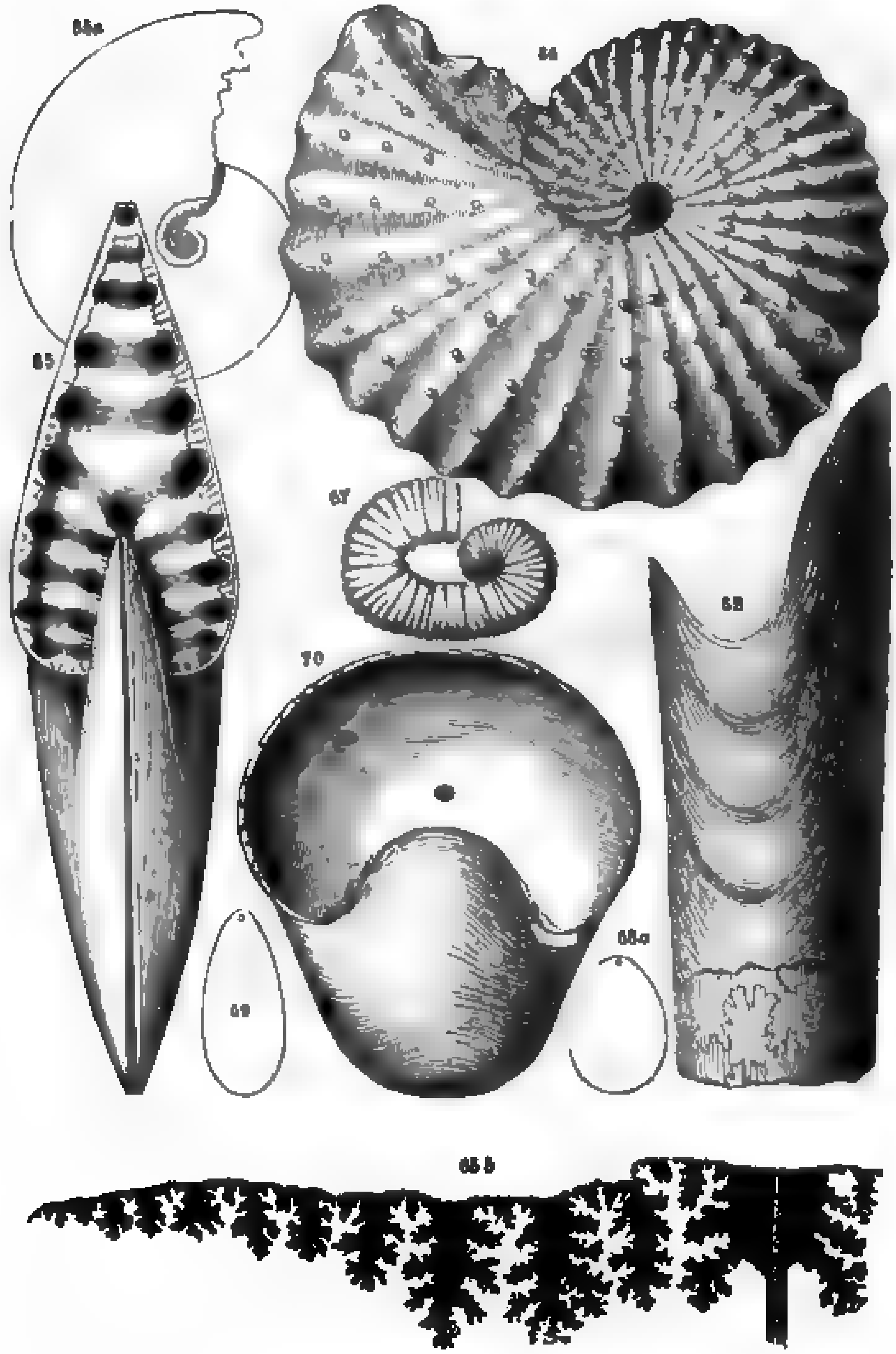
Conchifers.—Fig. 752, Exogyra arietina; 753, Ostrea Larva; 754, Exogyra costata; 755, Gryphæa vesicularis; 756, G. Pitcheri; 757, Inoceramus problematicus.

Figs. 758–764.



Gasteropods.—Fig. 758, Fusus Newberryi; 759, Fasciolaria buccinoides; 760, Aporrhais Americana; 761, Margarita Nebrascensis; 762, Nerinæa Texana; 763, 764, Bulla speciosa.

Figs. 765–770.



CEPHALOPODS.—Figs. 765, 765 *a*, 765 *b*, Ammonites Placenta; 766, Scaphites Conradi; 767, S. larvæformis; 768, 768 *a*, Baculites ovatus; 769, Section of B. compressus, reduced; 770, Nautilus Dekayi.

(d.) *Gasteropods.*—Fig. 758, *Fusus Newberryi* M. & H., from Nebraska; fig. 759, *Fasciolaria buccinoides* M. & H., from Nebraska; fig. 760, *Aporrhais Americana* (= *Rostellaria Americana*) Evans & Shumard, from Nebraska; fig. 761, *Margarita Nebrascensis* M. & H., from Nebraska; fig. 762, *Nerinaea Texana* Roemer, from Texas; *N. Acus* Roemer, from Texas; figs. 763, 764, *Bulla speciosa* M. & H., from Nebraska.

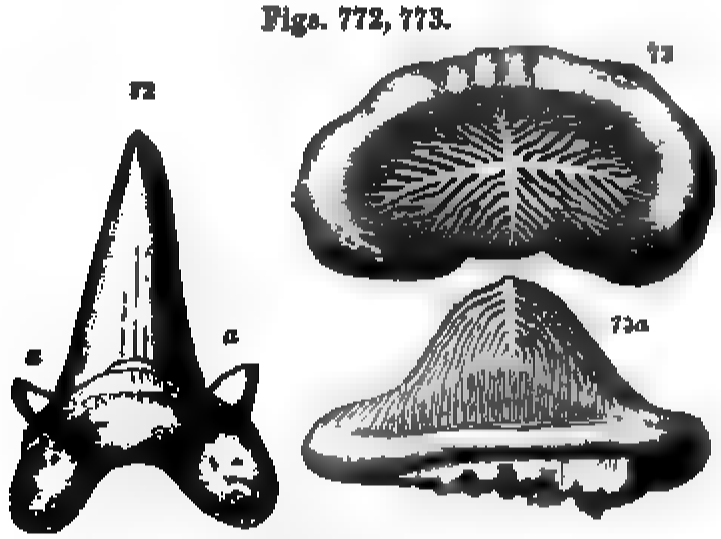
(e.) *Cephalopods.*—Fig. 765, *Ammonites Placenta* Dekay, from Atlantic border, Gulf border, and Upper Missouri, young specimen, natural size; fig. 765 *a*, outline side-view of the same, reduced; fig. 765 *b*, one of the septa of the same, natural size; fig. 766, *Scaphites Conradi* Morton, from the same localities as preceding; fig. 767, *S. larvæformis* M. & H., from Nebraska; fig. 768, *Baculites ovatus* Say, from New Jersey; fig. 768 *a*, outline of section showing oval form; fig. 769, outline of section of *B. compressus* Say, Upper Missouri; fig. 770, *Nautilus Dekayi* Morton, from the Atlantic and Gulf borders, and west of the Mississippi from Texas to Upper Missouri, and also reported from Europe, Chili, and Pondicherry in the East Indies. Fig. 771, *Belemnitella mucronata* Schlotheim, same U. S. distribution as preceding.

Fig. 771.

CEPHALOPOD.—Belemnitella mucronata.

4. Vertebrates.—(*a.*) *Fishes.*—Fig. 772, *Otodus appendiculatus*, from New Jersey. This genus *Otodus* (of the tribe of Squalodonts) is near *Carcharodon*,

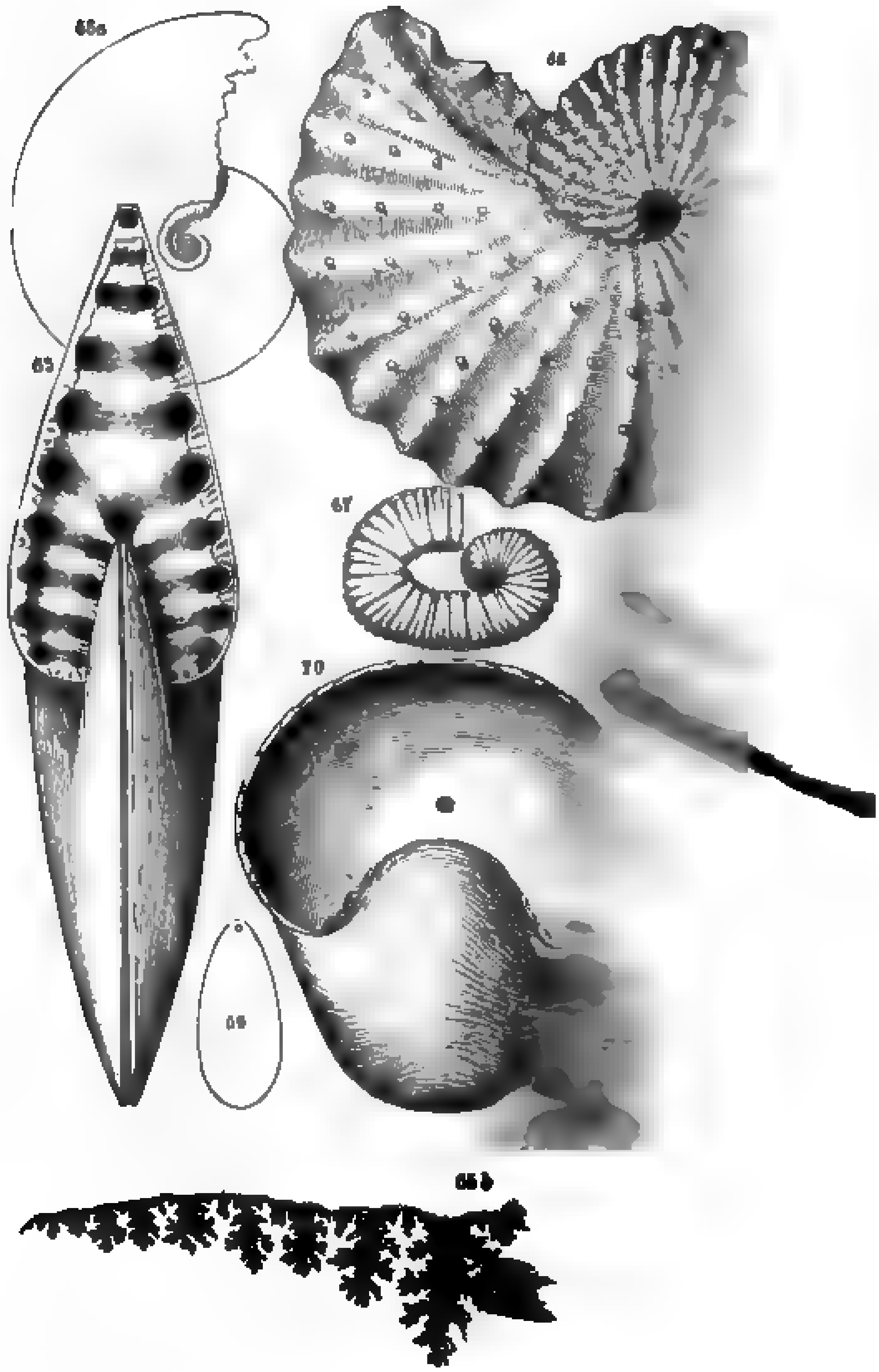
Figs. 772, 773.



SQUALODONT SELACHIAN.—Fig. 772, Otodus appendiculatus. CESTRACIONT SELACHIAN.—Figs. 773, 773 *a*, Ptychodus Mortoni.

but the teeth have a smooth margin without denticulations. *Oxyrhina*, another genus of this period, is like Otodus in this respect, but wants the small lateral teeth *a*, *a*. There were also species of *Lamna*, the teeth of which are

Figs. 765–770.



CEPHALOPODS.—Figs. 765, 765 a, 765 b, Ammoni
larvæformis; 768, 768 a, Baculites ovatus; 7
Nautilus Dekayi.

r Missouri: *Nautilus*
compressus, Heli-
nis. Alabama:
yphæa vesicularis,
mmonites Placenta,
. *Gryphæa lateralis*
ites Placenta, Bacu-
lites ovatus, Nautilus
plicata, Pholadomya
ostata, bones of *Mosa-*

ekayi, Amm. Placenta,
asaurus Missouriensis.
tilus Dekayi, Baculites
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N.

d distribution.

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-northeastward from near Port-
nbridge, and then northward to
nan Ocean. Like the Jurassic,
rance across the British Channel.
ance, in Sweden, and in southern,

nerally soft, and of various colors;
) the variety of limestone called
aterial, in beds of great thickness;

(4) other limestones, either loose or compact. Among the sandy portions the *Green-sand* beds are a marked feature, especially of the lower part of the formation. This is so eminently the fact that the Lower Cretaceous in England is called the *Green-sand*, although only a part of the layers are green, and in some regions none at all.

The Chalk often contains *flint* in nodules, which are distributed in layers through it like the hornstone in the earlier limestones. They are more or less rounded, and often assume fantastic shapes. Sometimes they resemble rolled stones; but in fact all are of concretionary origin. The exterior of the nodules for a little depth is frequently white, and penetrated by chalk, proving that they are not introduced boulders or stones, but have originated where they lie. Moreover, many chalk fossils are turned into flint, and it is common to find a mass of flint with a fossil as its nucleus.

The Cretaceous beds of Europe have been divided into—

1. The *Lower Cretaceous*, including in England the *Lower Green-sand*, 800 to 900 feet thick, and in other regions beds of clay, and limestone sometimes chalky.

2. The *Middle Cretaceous*, including in England (*a*) the clayey beds or marls called *Gault*, 150 feet thick, and (*b*) the *Upper Green-sand*, 100 feet.

3. The *Upper Cretaceous*, including in England the beds of Chalk, in all about 1200 feet: it consists of (*a*) the *Lower* or *Gray Chalk*, or *Chalk Marl*, without flint; (*b*) the *White Chalk*, containing flint; (*c*) the *Maestricht beds*, rough friable limestone at Maestricht in Denmark, 100 feet thick.

The subdivisions of the Cretaceous are variously named in different parts of Europe.

Lower Cretaceous.—Superior Neocomian of D'Orbigny (the Wealden being the inferior); also his Aptian; the Hils-conglomerat of Germany.

Middle Cretaceous.—1. *Gault*, Albian of D'Orbigny, Lower Plänerkalk of Saxony.—2. *Upper Green-sand*, Cenomanian of D'Orbigny, Lower Quadersandstein of the Germans.

Upper Cretaceous.—1. *Gray Chalk*, or *Chalk without flints*, Turonian of D'Orbigny, Hippurite Limestone of the Pyrenees, Upper Plänerkalk of Saxony. 2. *White Chalk*, or *Chalk with flints*, Senonian of D'Orbigny, Upper Quadersandstein? of the Germans, La Scaglia of the Italians. 3. *Maestricht beds*, Danian of D'Orbigny, Calcaire pisolitique near Paris.

In North America the *Earlier Cretaceous* corresponds, according to Meek & Hayden, to the inferior division of the Upper Cretaceous of Europe, or the Gray Chalk, with perhaps part or all of the Middle Cretaceous; and the *Later Cretaceous*, to the superior division of the Upper Cretaceous, or the White Chalk.

In mineral character the beds of each division vary much over Europe, the Chalk of England being synchronous with marls and solid limestones in Europe.

The Cretaceous of Great Britain is not found on any part of the Atlantic coast, excepting a small area in the vicinity of the Giants' Causeway. The beds of northern France spread eastward over Belgium and Westphalia, but not to

the Atlantic on the west; but farther south they occur at the deep indentation of the Bay of Biscay. They cover part of the Pyrenees, and reach into Spain in what has been called the *Pyrenean basin*, which in the Cretaceous period was a bay on the Atlantic. There is another sea-border deposit at Lisbon, in Spain. In southern France, over what is called the *Mediterranean basin*, the beds extend from the Gulf of Lyons along the Mediterranean coast, northeast to Switzerland, though with interruptions. The formation is found in the Juras and Alps, in Italy, Savoy, Saxony, Westphalia and Bohemia, northern Germany, Poland, middle and southern Russia, Greece, and other places in Europe. In Asia it has been observed about Mount Lebanon and the Dead Sea, the Caucasus, in Circassia and Georgia, and elsewhere; in northern and southern Africa; in South America, along the Andes, and on the Pacific coast, occurring in Venezuela, in Peru, at Concepcion in Chili, in the Chilian Andes at the passes of the Portillo and Rio Volcan at an elevation of 9000 to 14,000 feet, in the Straits of Magellan at Fort Famine in Fuegia.

II. Life.

The Life of the Cretaceous period in Europe resembled that of America, but was far more abundant. Nearly 6000 species of animals have been described, more than half of them Mollusks; whereas in America the whole number does not exceed 2000.

1. *Plants.*

Angiosperms and Palms were growing in Europe, and among the former there were the Willow, Walnut, Maple, and Holly. But the relics of Ferns, Conifers, and Cycads greatly preponderate; for the Cretaceous was properly the closing part of the era of Cycads. Vegetable remains of all kinds are rare, as the deposits are marine.

The microscopic Protophytes called Diatoms and Desmids are found in some of the beds, especially in the flint of the Chalk. The former have siliceous cases, as explained and illustrated on p. 271, and they may have contributed, as has been suggested, to the material of the flint nodules. The Desmids are not siliceous, but are still very common in the flint,—far more so than Diatoms (which are rare): the kinds which have been called Xanthidia are especially abundant; their forms are very similar to those from the Devonian hornstone figured on p. 271.

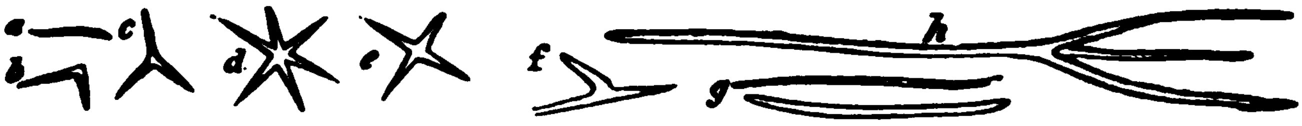
2. *Animals.*

The *Protozoans* of the family of Rhizopods (p. 163) appear to have been among the most important rock-making species of the Cretaceous period; for it is supposed that the Chalk itself is to a large extent made of their shells. According to Ehrenberg, a cubic inch

of chalk often contains more than a million of microscopic organisms, among which far the most abundant are these Rhizopods (called also Foraminifera and Polythalamia). Some of the species are represented in figs. 778–781.

The Sponges, also, were of great importance in the history of the Cretaceous rocks. They occur cup- or saucer-shaped, tubular, branched, and of other forms. One is figured in fig. 777. Their

Fig. 776.



Spicula of Sponges.

siliceous spicula are common in the flint, and have contributed, as well as Diatoms, towards the silica of which it was made.

Among Radiates, the Corals and Echinoids are mostly of modern types, and are far more numerous than in the Cretaceous of North America.

The same genera of Mollusks abound that are enumerated on p. 472. But the variety of Brachiopods, Gasteropods, and Ammonites is vastly greater than on the American continent. The Ammonites, and the uncoiled forms of the same family mentioned on p. 472, are particularly abundant. One English Ammonite (the *A. Lewesiensis*), from the Lower Chalk, has a diameter of a yard.

The genera of Gasteropods are to a greater extent modern genera than in the preceding period, and the proportion of siphonated species (having a beak) is nearly as great as in existing seas. The *Rudistes* (figs. 782–784) are very common in southern Europe and Asia Minor, and about eighty species have been described; only a single species—*Radiolites Mortoni*—has been found in England.

In the sub-kingdom of Vertebrates, there are Fishes of the modern order of *Teliosts*, and Sharks of the modern tribe of *Squalodonts*, as stated with regard to America (p. 473). One of these new fishes of the former group is shown in fig. 791. The Salmon and Perch families are represented among these earliest of Teliosts. Cestraciont teeth are very common.

The class of Reptiles in the earlier part of the Cretaceous period included the *Iguanodon;* both then and later there were three or four *Plesiosaurs;* an *Ichthyosaur;* another swimming Saurian, called *Polyptychodon* by Owen, nearly 50 feet long; several *Pterodactyls*, one of which, the *P. giganteus*, was 6 to 7 feet in the spread of its wings; a *Mosasaur*, 25 feet long (fig. 792); some Turtles. No true

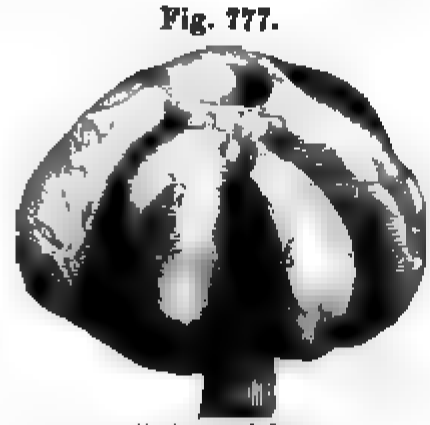
Crocodiles have been reported from the European Cretaceous beds, the earliest occurring in the Tertiary.

No remains of Birds or Mammals have yet been discovered.

Characteristic Species.

1. Protozoans.—(*a.*) *Sponges.*—Fig. 777, *Siphonia lobata*, from the Chalk. Figs. 776 *a* to 776 *h* represent the siliceous spicula of Sponges, showing some of the various forms they present. Over one hundred species related to Sponge occur in the Cretaceous strata of England. *Scyphia*, *Spongia*, and *Ventriculites* are the more common genera among the twenty enumerated.

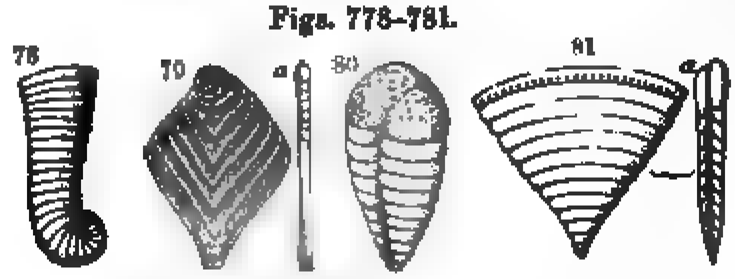
Fig. 777.



Siphonia lobata.

(*b.*) *Rhizopods.*—Fig. 778, *Lituola nautiloidea.* Fig. 779, *Flabellina rugosa*; fig. 779 *a*, profile of same. Fig. 780, *Chrysalidina gradata.* Fig. 781, *Cuneolina Pavonia*; fig. 781 *a*, profile of same. All are much magnified, the species being very minute, not exceeding half a line in length. Other genera are *Rotalia*, *Textilaria*, *Nodosaria*, etc. The Chalk formation of England has afforded over one hundred and twenty species and between twenty and thirty genera, and among them two species of the genus *Orbitolina*, an American species of which is represented in fig. 750.

Figs. 778–781.



Rhizopods.—Fig. 778, Lituola nautiloidea; 779 *a*, Flabellina rugosa; 780, Chrysalidina gradata; 781, *a*, Cuneolina pavonia.

2. Radiates.—(*a.*) *Polyp-Corals.*—Species of *Cyathina*, *Trochocyathus*, *Trochosmilia*, *Parasmilia*, *Micrabacia* (formerly Fungia), etc.

(*b.*) *Echinoderms.*—Species of the genera *Ananchytes*, *Cidaris*, *Diadema*, *Cyphosoma*, *Hemiaster*, *Cardiaster*, *Galerites*, *Holaster*, *Micraster*, etc.

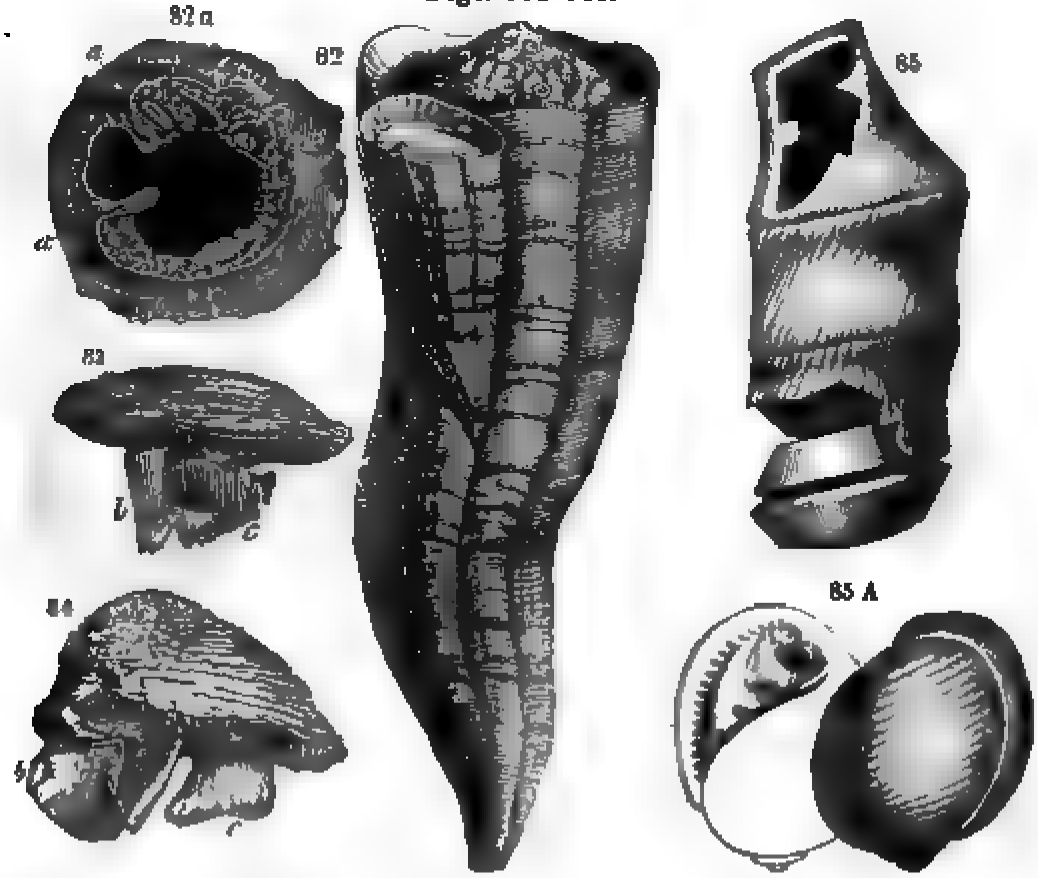
3. Mollusks.—(*a.*) *Bryozoans.*—Genera *Eschara*, *Escharina*, *Vincularia*, *Flustra*, *Cricopora*, etc.

(*b.*) *Brachiopods.*—Numerous species of *Terebratula*, *Terebratella*, *Terebratulina*, *Rhynchonella*, *Crania*, *Thecidia*, etc.

(*c.*) *Conchifers.*—Species of *Gryphæa*, *Exogyra*, *Inoceramus*, *Gervillia*, *Trigonia*,—all extinct; also of *Cardium*, *Astarte*, *Cardita*, *Corbula*, *Isocardia*, *Lima*,

Crassatella, Cyprina, Cytherea, Venus, Lucina, Panopæa, Avicula, Pecten, Neithea, Pholas, Spondylus, Tellina, Plicatula, and many other genera of existing seas,

Figs. 782–785.



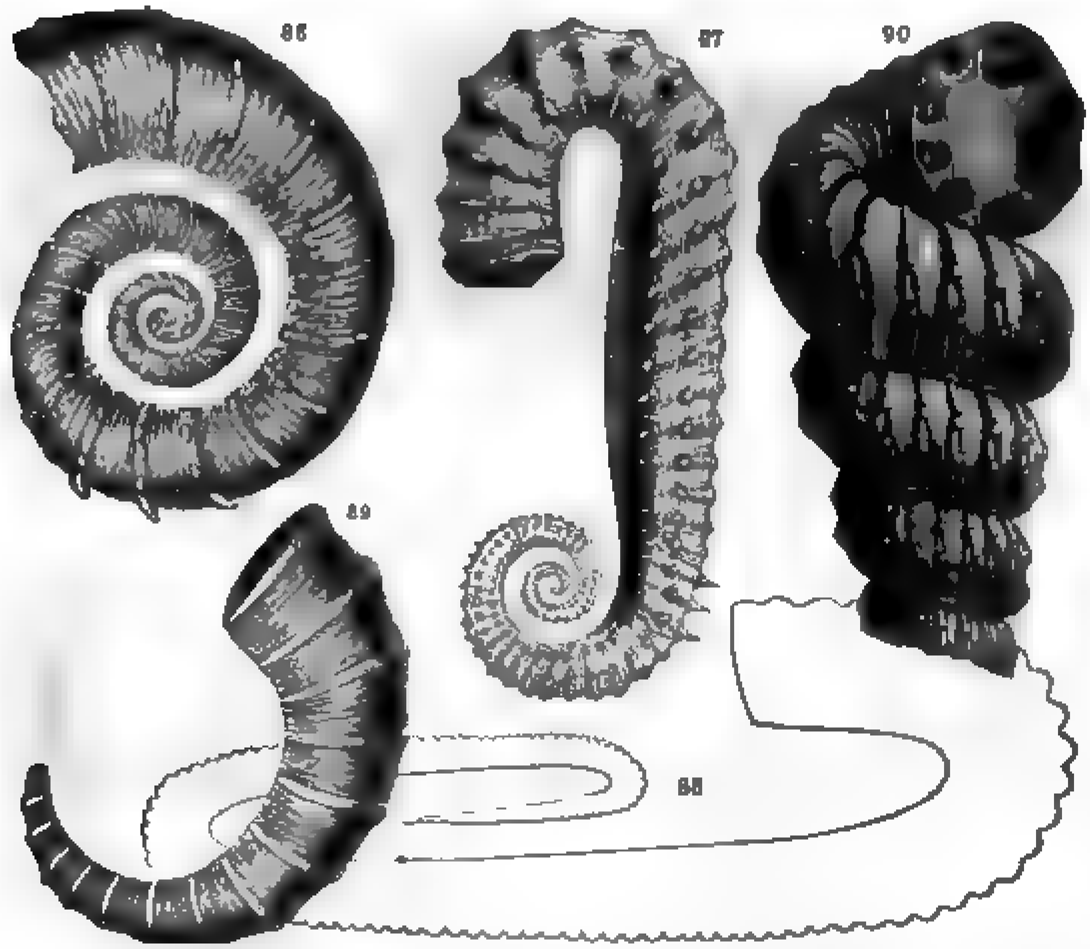
CONCHIFERS, *Rudistes* Family.—Fig. 782, Hippurites Toucasianus; 782 *a*, H. dilatatus; 783, Radiolites Bournoni, 784, Spherulites Hoeninghausi. GASTEROPODS.—785, Nerinæa bisulcata; 785 A, Avellana Cassis.

which give a modern aspect to a conchological cabinet of the Cretaceous period. The genera Crassatella and Neithea commence with the Chalk. Among the species of the extinct tribe of *Rudistes*, fig. 782, *Hippurites Toucasianus*, from the Upper Cretaceous, one of the most common species of southern Europe; fig. 782 *a*, *H. dilatatus*, vertical view, showing the interior of the lower conical valve, from the Lower Cretaceous; fig. 783, *Radiolites Bournoni*, upper valve in profile, from the Upper Chalk; fig. 784, *Spherulites Hoeninghausi*, upper valve in profile, from the Upper Chalk; *b*, *c*, in 783, 784, attachments of muscles.

(*d.*) *Gasteropoda.*—The extinct genera *Nerinæa, Actæonina, Actæonella, Avellana*, etc. The modern genera STROMBUS, BUSYCON, *Buccinum, Fusus*, VOLUTA, *Oliva*, FASCIOLARIA, OVULA, CYPRÆA, *Trochus, Nerita, Natica, Mitra, Conus, Cerithium, Bulla*, etc., showing a striking approximation to the present age in the closing period of the Mesozoic. (The genera in small capitals are some of those which make their first appearance in the Cretaceous period.) Fig. 785, *Nerinæa bisulcata* d'Archiac, from the White Chalk. Fig. 785 A, *Avellana Cassis*, from the Upper Green-sand; *a*, outline sketch, showing the toothed aperture.

(*a.*) *Cephalopods.*—Tetrabranchs (or Tentaculifers) of the Ammonite and Nautilus families.—Fig. 786, *Crioceras Duvalii*, from the Lower Cretaceous. Fig. 787,

Figs. 786–790.



CEPHALOPODS, *Ammonite* Family.—Fig. 786, Crioceras Duvalii; 787, Ancyloceras Matheronianus; 788, Hamites attenuatus; 789, Toxoceras bituberculatus; 790, Turrilites catenatus.

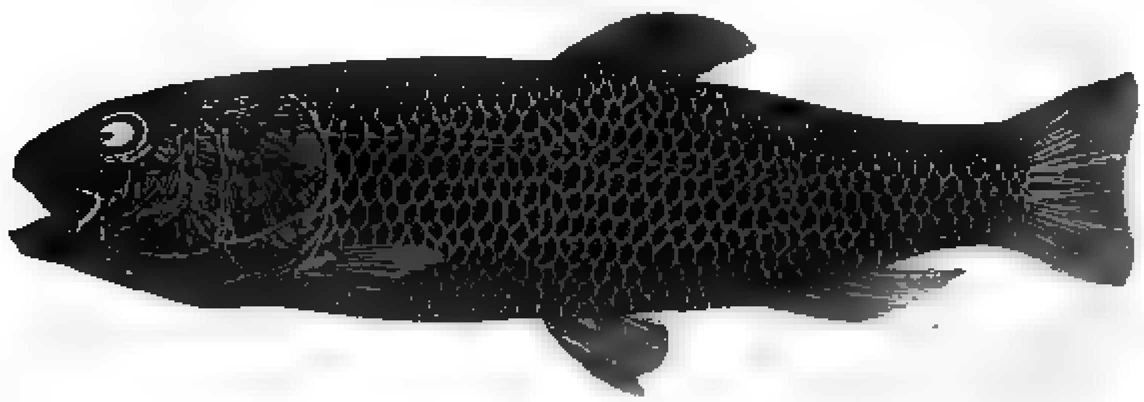
Ancyloceras Matheronianus, Lower Cretaceous. Fig. 788, *Hamites attenuatus*, Middle Cretaceous. Fig. 789, *Toxoceras bituberculatus*. Fig. 790, *Turrilites catenatus*, Gray Chalk. Also *Baculites* (as *B. anceps*, etc.).—Dibranchs (Acetabulifers): *Belemnitella mucronata*, a common species of the Upper Cretaceous; also species of *Belemnites* and *Conoteuthis*.

4. **Articulates.**—Worms of several genera. Crustaceans, of the Brachyural genera, *Grapsus*, *Podophthalmus*, *Podopilumnus*, *Arcania*, *Notopocorystes*, etc.; and the Macroural, *Scyllarus*, *Callianassa*, *Palæastacus*, etc. Of the tribe of Cirripeds, *Tubicinella*, *Pollicipes*. Also Ostracoids.

5. **Vertebrates.**—(*a.*) *Teliost Fishes.*—Fig. 791, *Osmeroides Lewesiensis*, from the Chalk at Lewes,—a fish of the Salmon family (Cycloid) related to the Smelt (genus *Osmerus*), and about fourteen inches in length. Another species of the genus, from the same beds, *O. Mantelli*, is eight or nine inches long. There were other Cycloids, of the genus *Clupea* (Herring), etc. Several species of *Beryx*, a genus related to the Perch (Ctenoid), occur in the Chalk: one, *B. Lewesiensis*,

is a broad fish, six to twelve inches long; another, *B. superbus*, sometimes thirteen inches long. About twenty-five genera of Cycloids and fifteen of Ctenoids

Fig. 791.

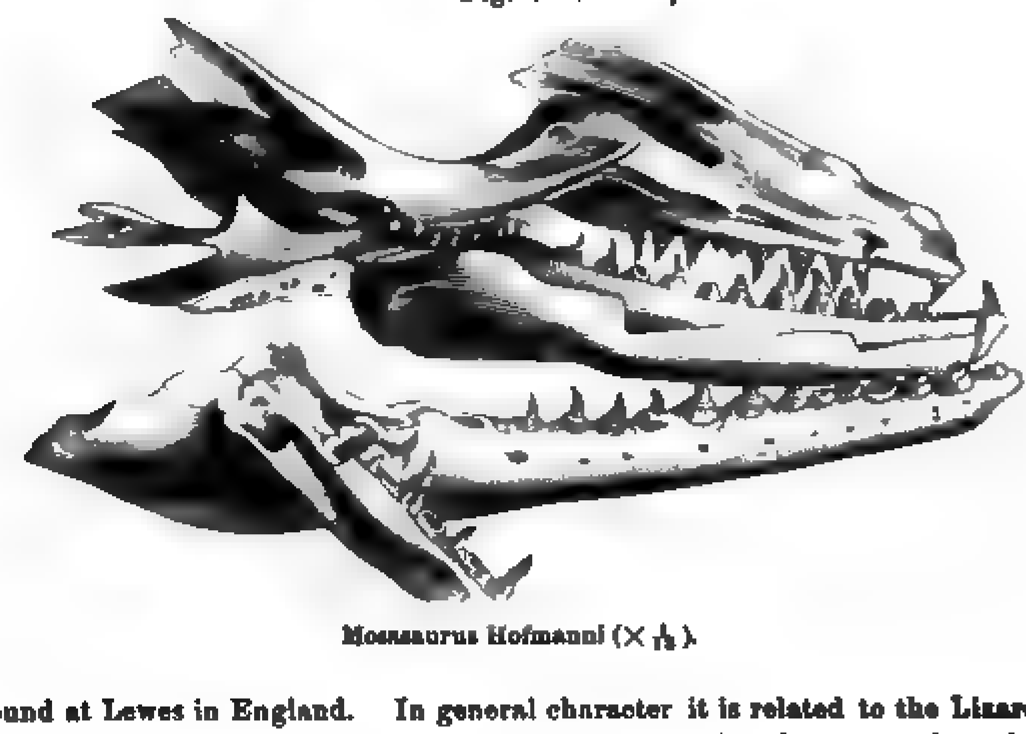


TELEOST.—Osmeroides Lewesiensis (× ¼).

have thus far been recognized in the Cretaceous. *Ganoids* were numerous in species, of the genera *Belonostomus*, *Caturus*, *Lepidotus*, etc., besides others of the Pycnodont family, *Pycnodus*, *Gyrodus*, etc. Sharks of the Hybodont family were sparingly represented; Cestraciont remains were very common, especially of the genera *Ptychodus* and *Acrodus*. Teeth of Squalodonts are occasionally met with, of the genera *Carcharias*, *Lamna*, *Oxyrhina*, *Odontaspis*, etc.

b. Reptiles.—Fig. 792, *Mosasaurus Hofmanni*, head, from the Chalk at Maestricht, one-eighteenth the natural size. Other remains of this species have been

Fig. 792.



Mosasaurus Hofmanni (× $\frac{1}{18}$).

found at Lewes in England. In general character it is related to the Lizards; but the short and stout humerus has led to the suggestion that it may have been a swimming species, and therefore a wholly new type.

Leiodon, *Raphiosaurus*, and *Coniosaurus* are other genera of the Upper Cretaceous. The genera *Ichthyosaurus*, *Plesiosaurus*, and *Pterodactylus* reach even into the Upper Cretaceous: *Iguanodon* occurs only in the Lower.

Species of wide geographical distribution.

The following species are reported from different continents (Bronn):—

Ostrea Larva,	N. A.; Eu.; India.
Gryphæa vesicularis,	N. A.; Eu.; S.W. Asia.
Exogyra levigata,	Eu.; Columbia, S. A.
Exogyra Boussingaultii,	Eu.; Columbia, S. A.
Inoceramus Crispii,	N. A.; Eu.
Inoceramus latus,	N. A.; Eu.
Inoceramus mytiloides,	N. A.; Eu.
Neithea Mortoni,	N. A.; Eu.; India; Peru, S. A.
Pecten circulans,	N. A.; Eu.; India; Peru, S. A.
Trigonia limbatus,	N. A.; Eu.; India.
Trigonia aliformis,	N. A.; Eu.; S.W. Asia; Columbia, S. A.
Trigonia longus,	Eu.; Columbia, S. A.
Hippurites organisans,	Eu.; S.W. Asia; Peru and Chili, S. A.
Nerinæa bisulcata,	N. A. (Texas); Eu.
Baculites anceps,	N. A.; Eu.; Chili, S. A.
Ammonites vespertinus,	N. A.; Eu.

The following Ammonites, according to D'Orbigny, are common to Europe and South America:—*A. Bogotensis*, *A. Dumasianus*, *A. Didayanus*, *A. galeatus*, *A. Vandecki*, *A. Tethys*, *A. prælonga*, *A. simplex*, besides others. The Echinus *Toxaster complanatus* is said to have the same range.

Relations of the Earlier and Later Cretaceous of America to the corresponding divisions of Europe.

The following tables of species in the Earlier and Later Cretaceous of America, showing their relations to species of the corresponding divisions in Europe, are from a paper by Meek & Hayden:—

Earlier Cretaceous W. of Miss. R.	Lower or Gray Chalk in Europe.
Ammonites vespertinus *Mort.*	occurs in Austria.
A. percarinatus *H. & M.*	probably ident. with *A. Woolgari* Mantell.
Scaphites Warreni *M. & H.*	scarcely distinct from *S. æqualis* Sowerby.
S. larvæformis *M. & H.*	same type as *S. æqualis*.
Nautilus elegans, *var.*	scarcely distinct from *N. elegans* Sowerby.
Inoceramus latus?	appears to be the same as *I. latus* Mantell.
I. problematicus	cannot be distinguished from *I. problematicus* Schlot.; reported also from the Upper Green-sand of Europe.

Species common to the Later Cretaceous of America and the Upper or White Chalk of Europe:—*Saurocephalus lanciformis*, *Lamna acuminata*, *Belemnitella mucronata*, *Neithea Mortoni*, *Ostrea Larva*, *Gryphæa lateralis*, *Gryphæa vesicu-*

laris, Nucleolites crucifer. The *Gryphæa vesicularis* is supposed by some to occur also in the Upper Green-sand and the Lower or Gray Chalk, but the form found in these lower portions is regarded by other authorities as a distinct species.

Genera common to the Later Cretaceous of America and the Upper or White Chalk of Europe:—*Mosasaurus, Saurocephalus, Callianassa, Pleurotoma, Fasciolaria, Cypræa, Pulvinites, Cassidulus.* There are also in the American Later Cretaceous the three genera *Busycon, Pseudobuccinum,* and *Xylophaga,* which have not yet been found as low as the Cretaceous in Europe.

III. General Observations.

1. **Origin of the Chalk and Flint.**—From the absence of vegetable remains and earthy ingredients, the abundance of sponges, and the general character of the fossils, it is supposed that the Chalk was formed at a distance of some miles from shore, where the water was at least 200 or 300 feet deep. The abundance of Rhizopod shells, as already stated, suggests that these were the main material; and the recent observation that the lead in deep-sea soundings on the north Atlantic has brought up sand composed almost wholly of minute Rhizopods, as published by Bailey, sustains the conclusion. These shells are like grains of sand in size, and are, therefore, ready for consolidation into a compact rock, needing no previous trituration by way of preparation; and thus they are especially fitted for making deep-water limestones. Corals require the help of the waves to reduce them to grains before a rock of compact texture can result. Moreover, the softness or imperfect aggregation of Chalk is probably due to this origin, and particularly to the fact that each grain is a *cellular* shell, or collection of air-cells, instead of solid. The coral reefs of the Pacific do not under ordinary circumstances give rise to chalk. The only chalk known in coral regions is on Oahu, at the foot of an extinct volcanic cone; and there it is probable that warm waters had some connection with its origin.

The Flint, as stated on page 481, has been attributed to the siliceous Infusoria of the same waters and the spicula of Sponges. In the soundings from the Sea of Kamtchatka, Bailey found microscopic siliceous shells of Infusoria (Diatoms) as abundant as the Rhizopods in the Atlantic, which favors strongly this opinion. The minute portion of silica which the alkaline waters of the ocean can dissolve—especially when the silica is in what is called the soluble state (p. 55), as is usual in these microscopic organisms—gives an opportunity for that slow process of concretion which might result in the flints of the Chalk. And the tendency to aggregation around some foreign body as a nucleus, especially when such a

body is undergoing chemical change or decomposition, explains the frequent occurrence of fossils within flints, and the silicification of shells.

2. **American Geography.**—The Cretaceous beds of New Jersey and of the rest of the border region of the continent, east and south, show in their structure and position, and in the character of their fossils, that they were formed either along a sea-coast or in offshore shallow waters. Farther west, the limestones of Texas indicate a clearer sea; while the soft sandy and clayey formations to the north are evidence that the same sea spread northward, but mostly of diminished depth.

The outline of the formation over the land points out approximately the outline of the sea in the Cretaceous period, and the general form of the dry land. This is presented to view in the accompanying map, in which the white part is the *dry land* of the

Fig. 792 A.

North America in the Cretaceous period, MO, Upper Missouri region.

continent, and the shaded the Cretaceous area, and therefore the *submerged* portion.

The line of the coast on the east extended from a point in New Jersey, to the southeast of New York City, across to the Delaware River, whose course it followed: this river, therefore, emptied into the Atlantic at Trenton, and the regions of the Delaware and Chesapeake Bays were out at sea. From the Delaware it continued southwestward, at a distance of 60 miles or more from the present coast-line between New Jersey and South Carolina. It next turned westward, being about 100 miles from the Atlantic in Georgia, nearly 200 miles from the Gulf in Alabama, and still more remote from the western Gulf shore in Texas. The Appalachians stood at a less elevation than now, by 60 to 100 feet.

The Gulf of Mexico, as the map illustrates, was prolonged northward along the valley of the Mississippi nearly to the mouth of the Ohio, making here a deep bay. Into it the two great streams entered, with only the mouth in common; and probably the Ohio was the larger, as its whole water-shed had nearly its present elevation and extent, while the Mississippi area was very limited. More to the westward, from the region of Texas, the Gulf expanded to a far greater breadth and length, stretching over much of the Rocky Mountain region, which was therefore so far submerged. It reached at least to the head-waters of the Yellowstone and Missouri (which rivers were, therefore, not in existence); and, judging from isolated observations in British America, the waters may have continued northwestward to the Arctic seas, at the mouth of Mackenzie River, where beds of this period occur.

This Cretaceous mediterranean sea spread westward among several of the elevations of the Rocky Mountain summits; and in New Mexico it spread still farther westward, over the region of the Colorado, to or beyond the meridian of 113° W.

By comparing the preceding map with that of the Azoic (p. 136), it is seen that the continent had made great progress since the opening of the Silurian age. But, as all this Cretaceous area was under Cretaceous seas, much was still to be added to the permanent dry land before its completion.

The great Interior Continental basin, which had been a limestone-making region for the most part from the earliest period of the Silurian, was still, in its southern part,—that is, in Texas,—continuing the same work; for limestones 800 feet thick were there formed. To the north of Texas, where the waters were shallower, there appear to have been none of the Echinoderms, Corals, Orbitolinæ, etc. which were common in Texas.

It has been noted that during the Triassic and Jurassic periods there were no marine beds formed on the Atlantic or Gulf borders

above the present level of the ocean, except sparingly in estuaries; and it has hence been inferred that the continent on the east and south, during that prolonged interval after the Appalachian revolution, stood with the coast-line situated outside of its present position (p. 441). And if it be true that the *earlier half* of the Cretaceous rocks are not represented among the beds of the Atlantic and Gulf borders, as now appears (p. 468), this prolonged interval must have continued until this much of the period had passed. The absence of sea-shore beds along a broad and shallow ocean border, like that of the western Atlantic, cannot otherwise be explained. The change submerging the present coast did not come on until the epoch of the Middle Cretaceous, and perhaps not till part of it had passed (p. 468). The lowest sandy beds, with their fossil wood, appear to mark the transition from the elevated to the submerged condition of the border, when the encroaching waters buried the vegetation of the land and the Cretaceous formation of the present coast had its commencement.

It appears from the above that the preceding remarks on the Geography of America in the Cretaceous period apply to the continent only in the later part of the period.

3. **Foreign Geography.**—The distribution of the Cretaceous beds over other continents shows that the lands were to a great extent submerged. The sea covered a large part of the region of the Andes, as well as of the Rocky Mountains, and both chains were to a great extent not yet flexed into mountain-shape; the Alps, Pyrenees, and Himalayas were also under water, or only in their incipient stages of elevation. Europe was mostly a great archipelago, with its largest area of dry land to the north: it resembled North America in the latter point, while widely differing in the former. The Urals and Norwegian mountains were the principal ranges of Europe, as the Appalachians and the Laurentian heights of Canada and beyond were in America. Western Britain was the high land of that region, and under its lee and that of other lands southwestward across the Channel, the new formations of western England and northern France were in progress on the borders of the German Ocean.

4. **Climate.**—The geographical distribution of species indicates a prevalence of warm seas in the northern hemisphere to the parallel of 60°, and in the southern to the Straits of Magellan. For the table on page 487 shows that several species are common to Britain, Europe, and either equatorial America, India, or the United States. The survey of the life of the period, therefore, as

far as now known, affords no evidence of the existence of the present cool temperature in the waters of the temperate zone.

The corals of the Cretaceous beds in England and Europe are so closely related to the reef-forming species of the present seas, that these concur with the other testimony in favor of warm seas. Moreover, as such reefs reach now to about the parallel of 27°, the coldest temperature of these regions, which is near 68° F., was probably the coldest temperature of the waters of the German Ocean, New Jersey shores, Mississippi basin, Vancouver's Island, Chili, and Straits of Magellan. They were within what is called the sub-torrid zone on the map of oceanic temperature.

The present position of the winter line of 35° F. on the Physiographic chart is probably near that occupied by the line of 68° F. in the latter part of the Cretaceous period.

There is a difference in the later Cretaceous between the species of northern and southern Europe, and also between those of the northern and southern United States, as explained on page 479, and this difference has been attributed to diversity of temperature. Some diversity of this kind undoubtedly existed; and it should be apparent in the fossils. But the particular facts referred to may not be sufficient to prove it. In North America, at least, the peculiarities in the life of the two regions, Texas and the Upper Missouri, may be owing rather to the difference in the horizon of the beds, and also to that of clearness or purity of the waters (Meek).

5. **Life**.—1. *Retrospective characteristics* (*allying the Cretaceous with the preceding period*).

1. Among PLANTS.—A preponderance of *Conifers*; numerous *Cycads*.

2. Among RADIATES.—Crinoids of the *Apiocrinus* family and others.

3. Among MOLLUSKS.—The genera *Thecidea, Gryphæa, Exogyra, Inoceramus, Trigonia, Nerinæa, Ammonites, Belemnites*.

4. Among VERTEBRATES.—*Pycnodont Ganoids, Cestraciont* and *Hybodont Sharks, Dinosaurs, Enaliosaurs, Pterodactyls*.

5. Species of plants and animals all extinct. Of the genera of plants only one-twentieth living; of the genera of Cephalopods, only one-twentieth; of the genera of fishes and reptiles, only one-sixth.

2. *Characteristics peculiar to the Cretaceous.*

1. Among PROTOZOANS.—Great multiplication of genera and species of Rhizopods and Sponges.

2. Among RADIATES.—Echinoderms of the genera *Ananchytes, Galerites*; Crinoids of the genus *Marsupites*.

3. Among MOLLUSKS.—Species of *Exogyra* and *Inoceramus* very common;

genera of the Ammonite family, *Crioceras, Hamites, Scaphites, Baculites, Turrilites*, first appear; also *Hippurites* and other genera of Rudistes.

4. Among VERTEBRATES.—The *Mosasaurus*, and a few other Reptiles, besides many genera of Fishes.

The prospective characteristics allying the Cretaceous with after-time are mentioned beyond, in connection with the General Observations on the Mesozoic.

GENERAL OBSERVATIONS ON THE MESOZOIC.

I. Time-ratios.

The estimate of the comparative lengths of the Palæozoic ages is given on page 386. According to it, the lengths of the Silurian, Devonian, and Carboniferous Ages are approximately as the ratio 3 : 1 : 1. The facts in European geology probably lead to the same result; the doubt arises from the uncertain thickness of the Primordial rocks.

The Mesozoic formations in America are too incomplete to be used in such a calculation. In the Western Interior region the whole thickness is only 5000 feet; and on the Atlantic border nothing definite is yet ascertained. The Mesozoic rocks of Europe and Britain afford more satisfactory data. The maximum thickness of the Triassic (in Germany) is about 3400 feet, 1000 of it limestone; of the Jurassic, 5200 feet, 1000 of it limestone; of the Cretaceous, 2400 feet, 1200 of it limestone: hence, for the whole Mesozoic, about 7800 feet for sedimentary beds, and 3200 for limestone. Making the calculation from these data, as on page 387, allowing 5 feet of sedimentary beds to correspond to 1 of limestone, the resulting number is 23,800; whence the *time-ratio* for the Palæozoic and Mesozoic is nearly 3½ : 1.

The time-ratio on the above data for the Triassic, Jurassic, and Cretaceous is 7400 : 9200 : 7200, or approximately, for the three periods, a ratio of 1 : 1¼ : 1.

Adopting D'Orbigny's conclusions with regard to the thickness of the European Cretaceous (which are far from established), the ratio between the Palæozoic and Mesozoic is approximately 2 : 1.

II. Geography.

Through the Mesozoic, North America was in general dry land, and on the east it stood a large part of the time above its present level. Rocks were formed on its southeastern and southern border, and over its great Western Interior or Rocky Mountain region. Europe at the same time was an archipelago, varying in the extent of its dry lands with the successive periods and epochs. Rocks

were in progress along its more southern borders and through its interior seas.

In America there are but few distinct formations, the Triassic and Jurassic making seemingly one continued series, and the Cretaceous another with three or four subordinate divisions. In Europe the number of epochal changes, or abrupt transitions in the rocks, is large,—much more so than in the Carboniferous age.

In America there are no limestones, and therefore no evidences of clear interior seas, except in the closing epoch of the Cretaceous in Texas, and some thin interpolations in the earlier formations. In Europe the Lias, and a large part of the Oolite and Chalk, are limestone formations.

The facts indicate great simplicity and but narrow limits in the oscillations of North America, and remarkable complexity and diversity of extent in those of Europe.

III. Life.

1. *Decline in Palæozoic Features.*

Decline in Carboniferous genera of plants.—Of the genus *Calamites* about 50 Carboniferous species have been described, only 3 or 4 Triassic, 2 Jurassic, and none of later periods. The genera of ferns *Pecopteris*, *Neuropteris*, *Sphenopteris*, and *Cyclopteris* are continued in the Mesozoic; but only one species in all—a *Pecopteris*—has been found in the Cretaceous beds.

Pecopteris had 50 species in the Carboniferous age, 5 or 6 in the Triassic period, the same in each the Jurassic and the Cretaceous; *Neuropteris*, 50 Carboniferous, 8 Triassic, 6 Jurassic, *none* Cretaceous; *Sphenopteris*, 75 Carboniferous, 20 Triassic and Jurassic, *none* Cretaceous; *Cyclopteris*, 34 Carboniferous, 4 Triassic, Jurassic *none*, Cretaceous *none*.

Decline in Crinoids.—There were over 500 species of Palæozoic Crinoids; of Jurassic, about 75; of Cretaceous, 15. Considering the time-ratio for the Palæozoic and Mesozoic, 3½ : 1, these numbers indicate an approximate equality between the eras. But it is still true that the Mesozoic is much less prolific in individuals.

Decline in Brachiopods.—The number of known Palæozoic species is about 700; of Triassic and Jurassic, 150; of Cretaceous, about the same. These numbers do not exhibit the fact of the decline. But it is strikingly seen in this: that the Brachiopods were *one-third* the whole number of Mollusks in the Palæozoic, and only *one-eleventh* in the Mesozoic. Moreover, the Mesozoic species belong extensively to the *Terebratula* family, which is eminently a

modern type; 125 out of the 140 Cretaceous species were of this family. Again, of the few Palæozoic genera that hold over into the Mesozoic, several die out before its close. This is true of *Spirifer*, *Spirigera*, *Cyrtia*, *Leptæna*. The last species of the *Spirifer* and *Leptæna* families lived in the Lias, and the Mesozoic representatives of these prolific genera are small compared with the earlier,—those of *Leptæna hardly larger than an apple-seed* (fig. 696 *a*).

Spirifer (and its allied genera) had 200 Palæozbic species, 12 to 15 Triassic, 9 Jurassic; *Leptæna*, and the closely-allied *Strophomena*, 75 to 100 Palæozoic, and only 5 of the former genus occur in the Lias, with which the type ends. *Rhynchonella* is one of the few Brachiopod genera having living species: there were about 120 Palæozoic species, 50 Jurassic, 30 Cretaceous,—indicating no diminution in relative number, considering the length of time for each era, though in number of individuals under the species the diminution is marked.

The decline of the Brachiopod type is further observed in the fact that the *Terebratula* family, which is the prevailing one in the Mesozoic, is low in grade, as shown in its simple internal structure and elongate form. The other Brachiopod groups cotemporaneous with it are nearly of the same inferior rank. Lingula, which began in the Primordial, and still exists, is one of the lowest types of the order.

Decline of the Cephalopod types of Orthoceras, Goniatites, and Conularia.—The simple *Orthoceras*, which began in the Potsdam period, had its last representative in the Triassic. The genus *Goniatites*, of Devonian origin, also ended in the Triassic. The genus *Conularia*, dating from the Lower Silurian, became extinct in the Jurassic.

Disappearance of vertebrate-tailed Ganoids.—Of Ganoids with vertebrated tails—the only kind in the Palæozoic—a few occur in the Triassic, and these are the last fossil species of the kind.

Decline of the type of Cestraciont Sharks.—This decline commenced in the Palæozoic and continues through the Mesozoic. It is now nearly an extinct family.

2. *Progress in Mesozoic Features.*

Culmination of the type of Cycads.—The plants of the Mesozoic were mainly *Ferns*, *Conifers*, and *Cycads*. The ferns belong to a type—that of Acrogens—which had passed its time of culmination in the Palæozoic. The Conifers were to have their fullest display in a later era. The Cycads are eminently Mesozoic. They appear to have begun near the close of the Carboniferous age, and passed their climax in the Jurassic period.

In the Mesozoic era, 10 or 12 Triassic species of Cycads have been recog-

nized, 70 Jurassic, and less than a dozen Cretaceous. Only a small part—probably *not a tenth*—of the species that actually existed would have become fossilized, as they are not confined to swampy soil.

Culmination of the Cephalopod type, and therefore of the type of Mollusks.—The Cephalopods are the highest of Mollusks, and in their culmination the culmination of the grand type of Mollusks took place.

In the Triassic period, before the disappearance of the Goniatites,—a Palæozoic form of the Ammonite type,—true *Ammonites* appeared, and the family rapidly multiplied in species and variety of forms. Between 800 and 900 species have been found fossil in the Mesozoic rocks. Besides these, the *Belemnite* family—characterized by an internal shell—commenced in the epoch of the Lias, and over 120 of its species have been gathered from the Jurassic and Cretaceous strata. There were also many species of *Nautilus*; so that the whole number of Cephalopods now known from the formations of the era is nearly 1200. Of this number about 950 were chambered shells of the Nautilus and Ammonite groups; while in existing seas there are only *four* species, and these belong to the single genus of Nautilus. The Ammonite and Belemnite families have had no living representatives since the Cretaceous period. It is to be noted that 950 is the number of species of chambered shells found *fossil*: it may be only a third part (or less) of those which were actually in the waters of the era. The age was therefore remarkable for the great expansion of the type of Cephalopods.

The number of species of the Ammonite family from the Triassic is about 100, from the Jurassic 400 (over 160 from the Liassic), from the Cretaceous about 400. The genus *Nautilus* has over 40 Mesozoic species.

In the families of chambered shells the expansion of the Tetrabranch Cephalopods (p. 156) is exhibited; and in the Belemnite, Sepia, and Calamary families, that of the Dibranchs.

The *Conulariæ* appear to have been the only representatives of the latter in the Palæozoic. They are generally referred to the group of Pteropods; but the large, thin, pyramidal shells, chambered at bottom, as Hall has observed, and admitting of some motion at the angles above, correspond better with the internal shell or osselet of a Cephalopod.

The type began in the straight *Orthoceras* with plain septa, and the half-coiled and equally simple *Lituite* of the Lower Silurian; it reached its maximum in the large and complex *Ammonite*, of the Jurassic, and the associated *Belemnite* and Cuttle-fishes; it declined in the Cretaceous, through the multiplication of the half-coiled forms of the Ammonite family (p. 485) and the straight *Baculite*.

The progress was from the simple and straight form through the coiled and complex, to the straight again, though without a return to the original simplicity in these straight shells. The *Nautilus*, which was associated with the *Orthoceras* in the Silurian, had the same simplicity in its septa; and this genus of chambered shells, out of the forty or more that have existed, is the only one in our present seas. The expansion of the type of Cephalopods was, therefore, not only an increase in variety of forms and number of species, but also in grade. With the Cretaceous period commenced the decline, and at the close of the period there was a sudden falling off in families, genera, and number of species. Whether any of the modern Cuttle-fishes (Dibranchs) are equal, or superior, to the highest Cephalopods of the Jurassic, it is difficult to determine. The modern genus *Nautilus*—representing the chambered species (Tetrabranchs)—is certainly of far lower grade than the Jurassic Ammonite.

It is therefore one of the great facts connected with the Mesozoic era that in its later half the sub-kingdom of Mollusks passed its period of culmination. But, while this is true of the sub-kingdom as a whole, it is not true of each of its subdivisions; for the inferior tribes of Conchifers and Gasteropods continue on the rising grade through the Mesozoic, and probably have their maximum display in the age of Man.

Culmination of the type of Ganoid Fishes.—The Ganoids, after the Triassic, lose the Palæozoic feature of vertebrated tails; and this is a mark of progress; for it is an example of that abbreviation of the posterior extremity which generally marks elevation in grade as well as progress in embryonic development.

In the Jurassic period, the number of species of Ganoids reached its maximum, and also the diversity of generic forms. The Ganoids are at present nearly an extinct tribe.

Over 300 Jurassic species have been described, besides nearly 50 Cretaceous, and as many Triassic. The ordinary Rhombifers culminated in the Jurassic, few of the genera continuing afterwards, while the Pycnodonts were numerous in the Cretaceous, and continue to be largely represented in the Cenozoic.

Culmination of the type of Hybodont Sharks.—The Hybodonts, which began in the Palæozoic, are numerous in Mesozoic species, especially in the Jurassic period, but almost extinct afterwards. Over thirty Triassic and seventy-five Jurassic species have been described. It is at present an extinct tribe.

Culmination of the type of Labyrinthodonts, and therefore of that of Amphibians.—The scale-covered Amphibians, called Labyrinthodonts,

which first appeared in the Carboniferous, have gigantic species in the Triassic, and at its close cease. The type of Amphibians is afterwards represented only by small species of the ordinary type without scales.

Culmination of the type of True Reptiles.—The Enaliosaurs or Swimming Saurians of the Triassic—the *Nothosaur* type—have the open skull of a Batrachian. In the Jurassic the type rises to the higher grade of the *Ichthyosaurs* and *Plesiosaurs*, when there were several genera and numerous species. In the Cretaceous the species are very few; afterwards there were none.

The Lacertians commence in the later Palæozoic, in species with the ichthyic characteristic of biconcave vertebræ, and retain it through the Triassic and in some Jurassic species. In the Jurassic and Cretaceous they come forth in many other species of great size without this low feature. After the Cretaceous only smaller species exist.

The Saurian type in the later Jurassic rises also to the grade of Dinosaurs, the highest in rank and among the largest of Reptiles; and these all disappear before the close of the Cretaceous period.

There is also an expansion of the type to flying forms, the Pterosaurs, in the Jurassic, and this type continues into the Cretaceous, but then ends.

Thus, in all the grand divisions there was a culmination and decline. Every genus becomes extinct at the close of the era except that of *Crocodilus*, which began in its last period.

The Reptilian type was unfolded in its complete dimensions, so as to parallel the later expansion of Mammals. The sea, air, and earth had each its species, and there were both grazing and carnivorous kinds of large and small dimensions.

The reality of this Reptilian feature of the age will appear from a comparison of England as it was in Reptilian times with England as it is, or with India, Africa, and America.

In a single era, that of the Wealden and Lower Cretaceous,—for the two were closely related in vertebrate species,—there were in the British dominions of sea and land four or five species of Dinosaurs twenty to fifty feet long, ten or twelve Crocodilians, Lacertians, and Enaliosaurs, ten to fifty or sixty feet long, besides Pterodactyls and Turtles. As only part of the species in existence would have left their remains in the rocks, it would be evidently no exaggeration to increase the above numbers two or three fold. But, taking them as made out by actual discovery, the facts are sufficient to establish the contrast in view. For, since man appeared, there is no reason to believe that there has been a single large Reptile in

Britain; in India, or the Continent of Asia, there are but two species over fifteen feet long; in Africa, but one; in all America, but three; and in the whole world, not more than six; and the length of the largest does not exceed twenty-five feet. The number of living species exceeding ten feet in length is only 16 or 18.

The Galapagos Islands are strikingly Reptilian at the present time. But they afford only four lizards, as many snakes, a turtle, and a large tortoise. The largest of the lizards, an *aquatic* species of the genus *Amblyrhynchus* (having feet, however, instead of paddles), is but three to four feet long.

If so large a number of species as above mentioned existed in Britain and its vicinity during the age of Reptiles, what should be the estimate for the whole world at that time? The question is a good one for consideration, although no definite reply can be looked for.

The culmination of the age of Reptiles occurred in the era of the Wealden. But, as in the case of Mollusks, the culmination of the grand type does not imply a culmination of all its subdivisions. There is no evidence that the inferior group of Snakes had begun to exist; and the Mesozoic species of Turtles are inferior in grade to those of the Cenozoic and the present age.

3. *Progress in Cenozoic Features.*

1. *Among Plants.*—(*a.*) *Angiosperms.*—The introduction in the Cretaceous of the great class of Angiosperms,—that to which all our common fruit and shade trees belong.

(*b.*) *Palms.*—The introduction in the Cretaceous of the tribe of Palms,—also eminent for its fruits and other useful products.

2. *Among Radiates.*—The introduction of the modern tribe of reef-forming Corals, the Astræoid Corals, and also the normal style of Echinoids, that is, those having only the normal number of vertical series of plates (p. 160), instead of an excessive number; as exemplified in the *Cidaris*, and other groups of the age.

3. *Among Mollusks.*—An increase in the number of modern genera of Conchifers and Gasteropods, and a larger proportion than before of siphonated Gasteropods (beaked univalves) and siphonated Conchifers.

Among modern genera the following begin in the Jurassic:—*Rimula, Planorbis, Paludina, Melania, Nerita, Pterocera, Rostellaria ?, Fusus, Tellina, Corbis, Anomia*, etc. In the Cretaceous:—*Neithea, Crassatella, Axinæa* (Pectunculus), *Petricola, Venus, Oliva, Ovula, Cypræa, Voluta, Turris* (*Pleurotoma*), *Busycon, Pseudobuccinum*, etc.

The number of non-siphonated (or integripallial) Conchifers in the Mesozoic, discovered up to 1849, according to a computation made by Bronn, was 2358, and of siphonated (or sinupallial), 1089; making the former over twice as numerous as the latter. Bronn gives for the corresponding numbers for living species 1480 and 1190. Of the integripallial Mesozoic species, *one-half* were Pleuroconchs (species having unequal valves), while in modern seas only about *one-fourth* are Pleuroconchs, the Orthoconchs amounting to 73 per cent.

4. *Among Articulates.*—(*a.*) *Crustaceans.*—The rise of the class of Crustaceans from Macrourans (Shrimps and Lobsters) to true Crabs. These Crabs belong to the division of square Crabs (or the Grapsoids); the higher divisions, the *Cancer* type (arched front) and *Maia* type (triangular Crabs), are still unrepresented.

(*b.*) *Insects.*—The unfolding of the class of Insects, nearly all the tribes being present in the later Jurassic,—even the highest tribe of Hymenopters, in the form of a species related to the Bee.

5. *Among Vertebrates.*—(*a.*) *Teliost Fishes.*—The introduction in the Cretaceous of the grand tribe of Teliosts, or common osseous fishes; and among the early representatives of the tribe there were species related to the Salmon, Herring, and Perch.

(*b.*) *Selachians.*—The introduction in the Jurassic of the modern tribe of Sharks,—the Squalodonts (genera *Sphenodus*, *Lamna*, *Oxyrhina*, *Notidanus*, etc.).

(*c.*) *Crocodiles.*—The appearance in the Cretaceous of the first species of the modern genus *Crocodilus.*

(*d.*) *Earliest Mammals,—Marsupials and Insectivores.*—The introduction in the Triassic of the earliest of Mammals, and their increase in genera in the Jurassic,—the species, Marsupials and Insectivores.

(*e.*) *Cetaceans, or Whales.*—The introduction in the Cretaceous of the earliest Mammals of the tribe of Cetaceans, or Whales.

4. *System in the Progress of Life.*

Comprehensive Types.—Next to the Labyrinthodonts, remarked upon on p. 395, the *Cycads* are the most marked example of a comprehensive type in the Mesozoic. These plants—the characteristic species of the era—are related in some fundamental points both to the Ferns and Palms. They are like the former in that the leaves are rolled into a coil in the bud, and unroll on expanding; they resemble the latter in the form of their foliage and in the general habit of the plant. The first was a retrospective feature, for the Ferns were of Palæozoic origin; the latter was prospective, the Palms not having yet appeared.

The Marsupials are another example under this head. They

approach Reptiles and Birds in their semi-oviparous character; they are like the former also in the sacrum consisting of but two vertebræ combined; and among the lower species of later time the birds are represented by the Duck-bill (*Ornithorhynchus*) and Reptiles by the *Echidnus*. Along with these inferior features there were the dominant characteristics of the true Mammal.

A subordinate example of the comprehensive type is seen in the *Rhynchosaur* of the Trias, which combined the characteristics of the Saurian with the bill, and partly the skull, of a Turtle. Whether it had paddles or not is undecided.

All the examples here mentioned, it will be observed, made their appearance in the Trias.

The Pterodactyls combine with the Saurian characteristics peculiarities of birds; but they are not satisfactory examples of a comprehensive type, any more than the Bats among Mammals: they are adaptations of the Reptilian type to the air.

Earliest Mammals.—On p. 396 several examples are mentioned in which the early species of a group were partly from the *lower* of its two grand subdivisions, and partly from the inferior grades of the *higher*. If, in a similar manner, Mammals are divided into Marsupials (the *lower* division) and Non-marsupials (the *higher*), the earliest kinds embrace species of the former, along with Insectivores, a tribe in the inferior or Microsthenic division (p. 423) of the latter.

The species of the higher group are not necessarily from its lowest subdivision. Below the Insectivores there is the Sloth tribe, or that of Edentates; and this low group is not known to occur before the Cenozoic (Tertiary). In the same manner the Reptilian associates of the early Amphibians were Lacertians and Enaliosaurs, and not Snakes of the *inferior* subdivision of True Reptiles. The earliest-known Snakes are found in the Tertiary.

In the limited Fauna and Flora of early time *the species of the higher group are such as blend harmoniously with those of the lower.* This principle is illustrated on p. 396. In the case of Mammals, the Marsupial Insectivores harmonize better with the Non-marsupial Insectivores than they would with Sloths, and the Labyrinthodonts better with Lacertians than with Snakes. Again, the air-breathing Vertebrates of the Mesozoic, made up of oviparous Reptiles, semi-oviparous Mammals, and viviparous Mammals, are an harmonious assemblage. The fauna of an era is not well appreciated unless considered apart from those of other periods. An attempt to classify the living species as they would have appeared

to a mind in the age itself, having in view co-existing species and those that had gone before, is an essential preliminary to a correct apprehension of the life of each epoch.

5. *Disturbances during, and at the close of, the Mesozoic Era.*

In American history we have found evidences of disturbance in the tilted beds of the Connecticut River sandstone and the intersecting trap, as mentioned on p. 430. The period of the uplift is not ascertained; but it is evident that it preceded the Cretaceous period, as the Cretaceous rocks are undisturbed and without trap dikes. The destruction of species was complete, as none pass up into the Cretaceous.

The Cretaceous strata are all concordant in stratification. They indicate oscillations of level in the land and sea, but no violence at any interval during their deposition.

In Europe, as in America, the Palæozoic closed amid scenes of great disturbance and metamorphism. But during the progress of the Reptilian age the rocks, Triassic, Jurassic, and Cretaceous, appear to have been laid down for the most part conformably, with few examples of non-concordance, yet with those variations in their distribution that arise from variations of the ocean's level, as a consequence of gentle heavings of the earth's crust. There were thus elevations and depressions, producing the varying geography of the age, and successive destructions of species attending them, so that but an extremely small number of Liassic species pass up into the Oolite,—D'Orbigny says *none*,—and less than a dozen from the Jurassic to the Cretaceous; while the many subordinate epochs also were separated by general destructions, and peopled mostly by independent creations.

A disturbance took place between the Triassic and Jurassic periods in the region of the Thuringian Forest and the frontiers of Bohemia and Bavaria, the Jurassic beds overlying unconformably the Triassic: it is named by De Beaumont the *System of the Thuringian Forest*, and the direction mentioned is N. 50° W. Again, between the Jurassic and Cretaceous was formed De Beaumont's *System of the Côte d'Or*, having the direction N. 50° E.

The rocks of the Cretaceous and Jurassic are still very nearly horizontal in the great Anglo-Parisian region (the part of the German Ocean basin exposed to view).

The close of the Mesozoic era (or that of the Cretaceous period) was a time of disturbance unequalled since the close of the Palæozoic. Its effects are apparent,—

1. *In the destruction of life.*—No species, either in Europe or

America, is yet ascertained to have lived through the interval into the Mammalian age. Moreover, very many of the genera and some large families of species abounding in the Chalk are afterwards unknown, as has been already illustrated.

2. *In the distribution of the Cretaceous beds, as contrasted with those of the succeeding age.*—The Cretaceous seas covered the summits of parts of the Rocky Mountains and Andes. These lofty ranges have since been raised, and in part the elevation took place before the epoch of the Tertiary, whose marine beds lie at their base. Vast additions were thus made to the continents. From similar evidence it is known that the Pyrenees and Carpathians were raised into existence in the early Tertiary; and, while the Alps were in part of much later date, dislocations and elevations in the French Alps (*Mount Viso system* of De Beaumont) and the southwestern extremity of the Jura are traced to the middle or close of the Cretaceous. The surface of the Chalk of England is described as bearing marks of very extensive denudation, proving its elevation above the ocean in which it was formed before the Tertiary beds were deposited.

The evidence thus far collected is sufficient to sustain the statement that the epoch following the close of the Mesozoic era, like that after the Palæozoic, was one of revolution, and that the disturbances ended in extensive additions to the dry land of the globe.

But there is no reason to believe that the revolution was the result of an instantaneous movement. It was probably slow in progress, like others that had preceded it, and may have occupied a long age. Moreover, this era of disturbance was continued through the Tertiary period, during which the Pyrenees, Alps, Apennines, Himalayas, and other mountains reached nearly to their present altitude above the level of the ocean, and the continents attained in general their full extent.

The relative positions of the Cretaceous beds and marine Tertiary in North America (see map, p. 133) afford data for estimating the change of level after the Mesozoic era on the North American Continent. In this way we learn that on the Atlantic border the change was slight, and in general there was no upward movement; for the Tertiary formation mostly covers the Cretaceous. On the Gulf border in Alabama the rise could not have exceeded 100 feet; along the Mississippi, towards the mouth of the Ohio, it may have been 275 feet; and about the head-waters of the Mississippi, the great central plateau of the continent, 1700 feet.

West of the Mississippi, as already stated, the changes were

great, raising out of the sea a large part of the Rocky Mountain region. About Santa Fé in New Mexico, the Cretaceous beds are 6000 and 7000 feet above the sea; near Pike's Peak, 4500 feet; at Deer Camp on the North Platte, nearly 6000 feet; on the Big Horn Mountains, 6000 to 7000 feet; about Fort Benton on the Upper Missouri, and westward along the base of the mountains, 4000 to 6000 feet; in the vicinity of the Wind River Chain, 6800 feet. Hence, the whole rise since the close of the Cretaceous about the central region of the Rocky Mountains has amounted to nearly 7000 feet; and from this it decreased eastward towards the Mississippi and westward towards the Pacific. What part of this elevation in these mountain-regions took place immediately after the Mesozoic era, and how much later, is not easily ascertained. Part was unquestionably of later date, as Hayden has shown. This subject comes up again under the general observations on the Cenozoic.

The elevation of the great plateau appears to have been a gradual upward movement without much disturbance of the rocks. Through 3000 or 4000 feet, nearly to the base of the summit-mountains, as Hayden observes, the beds are nearly or quite horizontal. But along the sides of the mountains there is some dip, though usually small. On both the east and west sides of the Wind River Chain, and about the Big Horn Mountains, the dip does not exceed one or two degrees. West of the Black Hills, however, and in some other localities, the beds incline 10° to 25°.

Causes of the Destruction of Life.—The complete extermination of species at the close of the Cretaceous period has not been fully explained. It was probably connected with the great changes of level which took place at the time, as has been shown, over the Eastern and Western continents. The elevations to the north may have been even greater than has been supposed; for elevations do not leave as indubitable a record as subsidences. In North America there are no Tertiary beds known north of southern New England on the east, and none in the Arctic,—indicating, apparently, that the whole area was above the sea then, as now. The emergence of the continents would have extinguished the life of the continental seas; and a large increase of land in the higher temperate and polar regions would have given completeness to the destruction by causing a colder temperature in both the air and the waters. It is therefore most probable that the destruction was due (1) to the more or less complete emergence of the continents and accompanying elevation of mountain-ranges; and (2) to a change of climate and oceanic temperature,—both the air and oceans being rendered colder than in the Mesozoic era.

IV. CENOZOIC TIME.

It has been observed that before the close of the Mesozoic the medieval features of the era were already passing away. The Cycads had begun to give place to Oaks, Willows, and Palms; the ancient type of Ganoids, to Salmon, Perch, and Herring: and the corals, Echini, and shells were in a great degree allied to those of existing seas, though all of extinct species. But, notwithstanding these progressing changes, the Mesozoic aspect continued on to the end, appearing prominently in the multitudes of Ammonites and Belemnites, in the predominance of Cestracionts and Ganoids among fishes, and in the supremacy of the great class of Reptiles. Even the little Mammals which appeared among the Reptiles bore the mark of the age; for the larger part, at least, approximated to the oviparous Reptiles and Birds in being themselves of a semi-oviparous type, the Marsupial.

But these Mammals were prophetic species; and with the opening of a new era the Reptiles dwindled in numbers, variety, and size, and Mammals in their turn became the dominant race. At the same time, types much like those of the age of Man were multiplied in all departments of nature. As the era advanced, the first of living species appeared,—a few among multitudes that became extinct, and afterwards a larger proportion; and before its close, nearly all kinds of life, excepting Mammals, were identical with those of the present era. As the Palæozoic or *ancient* life was followed by the Mesozoic or *Medieval*, so now there was as marked a change to the Cenozoic or *recent* life and world.

Cenozoic time embraces only a single age, the age of Mammals.

MAMMALIAN AGE.

The age of Mammals is divided into two periods:—

1. The TERTIARY, in which all the Mammalian species are extinct, and the proportion of living Invertebrates—Radiates, Mollusks, Articulates—varies from none in the early part of the period to 90 per cent. in the latter part.

2. The POST-TERTIARY, in which nearly all the Mammalian species are extinct, but the Invertebrates are nearly all living, not over 5 per.cent. being extinct.

The name Tertiary is a relic of early geological science. When

The submarine valley of the Hudson River (p. 441) may have been formed during the same elevation of the continent in which the fiords originated. The Connecticut River valley is also distinct over the same submerged plateau, running south from the channel east of Long Island.

(6.) That an elevation of the continent over its northern regions of a few thousand feet is sufficient to account for the existence of a *Glacial epoch* in the earth's later history; and an elevation of 5000 feet is as probable as a subsidence of 5000 feet.

The main difficulty encountered by the Glacier theory is that the land to the north has not the slope supposed necessary to give glaciers a southward movement, and it would not acquire this slope by any probable elevation.

During a Glacial epoch of the kind here supposed, the whole northern portion of the continent down to the southern limit of the Drift would have been covered by a vast and almost uninterrupted glacier. This is now the case in North America with the return of nearly every winter. But the depth, instead of being, as now, but a few feet, and that mostly of snow, must have been, judging from the height on the hills to which the striæ extend, at least 4000 or 5000 feet, and the material, as in all such thick accumulations, would have been ice; and above this there may have been other hundreds of feet of snow. Glaciers of so vast extent and thickness would have moved downward wherever the conditions would permit, like the glaciers of the Alps,—and all the more readily for their enormous weight.

There are two conditions to be considered:—*First*, the one already mentioned,—the existence of some degree of slope in the surface; *second*, the absence of barriers to prevent descent along the slope.

Now, to the northward over the continent, with no lofty ranges, there would have been a universal barrier in the ice and snow of the universal glacier. But on the south the ice would have had a limit, caused by the climate. Motion would therefore have been mainly to the southward, if it took place in any direction.

The requisite slope exists now in New England and eastern New York, along the Connecticut valley, east of the summit of the Green Mountains, and along the Hudson River valley west of the summit. The motion of a great glacier along either valley would have given the same direction to the striæ and to the lines of boulders which actually exists. It would also have scored the sides and tops of the minor valleys and ridges, regardless of their courses and declivities; and as the glacier finally melted away it might have left its *moraines* as trains of stones on the surface, crossing deep valleys obliquely, or in any direction, and blocks of thou-

sands of tons' weight might have been lodged on the tops of ridges, miles away from their place of origin. Moreover, the Green Mountain side of the Connecticut valley would naturally have given that more eastern direction to the striæ observed about the higher summits (p. 540), because the general slope is eastward; while below these more elevated points the southward inclination of the great valley itself would have directed the movement of the extended glacier.

In the vicinity of Penobscot Bay, Maine, according to J. De Laski, there are groovings, polishings, and other related effects, in perfection, which prove beyond question the former existence there of an extensive glacier,—probably one of the many terminations of the continental glacier.

Switzerland, besides its examples of small modern glaciers, affords evidence of a great glacier in some former time which serves to illustrate the condition in the Glacial epoch in America. At the time referred to (supposed to be later than the Glacial epoch), a glacier stretched from Mt. Blanc and other Alpine heights over the Swiss plains to the Jura Mountains on the borders of France, having underneath it the sites of Lake Geneva, Lake Neufchatel, and other Swiss lakes. The declivity of the Juras facing the Alps was covered, to half its height in many places, with the boulders that were transported by the ice; and one of them—the *Pierre-à-bot*, a mass of granite (or more properly *protogine*)—is 62 feet long by 48 broad, and contains about 40,000 cubic feet, equivalent to a weight of 3000 tons. The transportation of this and other such blocks has been attributed to icebergs. But Guyot, by an extensive exploration of the mountains and plains, succeeded in tracing out the lines of moraines across the plains; and, by observing the kinds of rocks characterizing the several lines, followed each up to the peak or peaks in the Alps from which it was derived. He proved in this way that the *Pierre-à-bot* and other similar masses of the same part of the Juras came from Mt. Blanc, and that the red sandstone boulders accompanying the granitic on the Juras were from the Aiguille Rouge, a neighboring summit. By this means he found that the order of succession in the peaks is repeated in the order of the lines of rocks over the lowlands, just as would have been the fact had these lines been originally the moraines of a glacier. He further ascertained that the great glacier from Mt. Blanc which bore on its surface for ninety miles the *Pierre-à-bot*, and multitudes of other masses, small and great, left the vale of Chamouni (the present terminus of the Mt. Blanc glaciers) by the valley of the Trient, and so passed northward into the valley of the Rhone; thence it spread still northward and westward across the Lakes of Geneva and Neuf-

chatel to the Juras. The Alpine heights are in many places deeply grooved, on a magnificent scale, to a height of 10,000 feet above the sea (as well seen in the valley of the Aar), showing that this was the height of the ancient glacier in the mountains,—while its depth or thickness must have been 4000 or 5000 feet. The slope from Mt. Blanc to the Juras back of Neufchatel averages very nearly one degree,—equivalent to one foot in sixty. There are other blocks in the Alps still larger than the *Pierre-à-bot*. One of them, at Steinhof, near Seeberg, contains 61,000 cubic feet, and has travelled from its original site nearly 200 miles.

These facts from Switzerland seem to be but a repetition of those observed in connection with the Drift epoch in America and other regions. They will be better appreciated after a perusal of the pages on Glaciers under the head of Dynamical Geology.

The Glacier theory most satisfactory, but the Iceberg theory required, in some cases, for the borders of Continents.—In view of the whole subject, it appears reasonable to conclude that the Glacier theory affords the best and fullest explanation of the phenomena over the general surface of the continents, and encounters the fewest difficulties. But icebergs have aided beyond doubt in producing the results along the borders of the continents, across ocean-channels like the German Ocean and the Baltic, and possibly over great lakes like those of North America. Long Island Sound is so narrow that a glacier may have stretched across it.

In Europe icebergs were evidently more extensive in their operation than in America. Glaciers have probably continued there in action from the time of their first appearance on the continent to the present day; and the Glacial era on that continent may not, therefore, be the well-defined period that it is in North America.

Geography.—*The Glacial epoch an epoch of high-latitude elevation.*—The evidence presented with regard to an epoch of unusual cold in the early Post-tertiary, when glaciers and icebergs prevailed vastly beyond their existing limits, leaves little doubt that the epoch was one of some increase of elevation throughout the drift or cold latitudes. The elevation may not have affected every part, but yet was sufficient to make the northern and southern hemispheres alike in their glacial phenomena. This evidence is strengthened by the fact that fiords occur in the same latitudes, north and south.

The author's views on fiords and the epochs of the Post-tertiary period were first published in the Amer. Jour. Sci. [2] vii. 379, 1849, and xxii. 325, 346, 1856.

See further, on Glaciers, Appendix D.

2. CHAMPLAIN EPOCH.

American.

The Champlain epoch is so named from beds of the epoch on the borders of Lake Champlain.

The term Champlain is applied to marine deposits of the epoch by Hitchcock in the Report on the Geology of Vermont.

I. Rocks: kinds and distribution.

Distribution.—The distribution of the formations of the Champlain epoch may be treated of under three heads: (*a*) *river-border* formations; (*b*) *lake-border* and other lacustrine formations; (*c*) marine or *sea-border* formations.

(*a*.) *River-border formations.*—From New England to California and Oregon, over the wide range of the continent, the river-valleys contain extensive alluvial formations. The beds overlie the drift of the Glacial epoch, where they occur together, as has been observed in several places; and they generally reach to a height far above that of present alluvial action. The Connecticut River, Hudson, Mohawk, Ohio, Sacramento, Willamette, and numerous other valleys afford fine opportunities for their study.

The formation along the course of any river has nearly a flat summit, and is the foundation of the elevated plateau of the valley; and very often there are plains at one or more levels besides the upper, so that the whole makes a series of terraces.

The sketch on p. 548 (fig. 830), from the Connecticut River valley some miles south of Hanover, N.H., represents the general appearance of the alluvial formation with its terraced surface. The descents of a road in the neighborhood of rivers are mostly from the top of one of the tables down to the bed of a streamlet, the origin, perhaps, of the cut; and the ascent on the opposite side carries the road to the upper level again. The borders of all such cuts, therefore, and of river-valleys generally, are excellent places for observing the features of the alluvial landscape and studying its beds. Up or down the stream, horizontal lines may often be traced for miles, marking the limit of one or more of the several terraces bordering it. Many villages in the vicinity of rivers owe a large part of the beauty of their sites to these natural terraces of the country.

This alluvial formation appears to characterize all the river-valleys of the continent over the drift-latitudes, and also, to a less extent, still farther south in the latitudes of Kentucky and Ten-

nessee, so that it may be said to have a continental distribution. It is not yet ascertained whether it is distinguishable by greater elevation from the present river-flats in the valleys of the States bordering on the Gulf of Mexico.

It generally accompanies the whole course of a stream from its mouth to its source in the mountains. It follows even all the tributaries, and fails only where the stream is a steep mountain-torrent or is bounded by lofty walls of rock. A map showing the distribution of the formation will hence be like that of the rivers, with the

Fig. 830.

Terraces on the Connecticut River, south of Hanover, N.H.

same variations of course for each, excepting the minor irregularities and a much greater breadth.

These valley alluvial beds contain no traces of marine relics, and no evidence whatever of any but a fresh-water origin.

(*b.*) *Lake-border and other lacustrine formations.*—Formations similar to those along river-valleys exist about lakes in the same latitudes. They are often called *beaches*, or *lacustrine* formations. Where a river flows into a lake, the elevated plain of the river-alluvium is generally continuous with that bordering the lake.

It is not safe to conclude that all the upper lake-border formations belong to the Champlain epoch, any more than that all elevated sea-beaches containing recent shells are of the same. Yet in North

America these Champlain formations of all kinds over the continent are so combined in system, both as to extent and elevation, that it is generally not difficult to arrive at a right decision on this point. There are many examples of the direct passage of the high plains along a river into that of the lake, or into that of the sea-border, where the river empties into the one or the other, in which the mutual relations and dependence of the whole cannot be doubted.

Besides these border formations of lakes, there are also, overlying the Drift in many places, beds of marl or calcareous earth formed from fresh-water shells in the ponds and smaller lakes of the epoch. This *shell-marl* is of great value as a fertilizer. Beds of peat were often in progress afterwards in the same ponds as they were gradually drained and became marshes. The shells are all of existing species.

In elevated regions without rivers or lakes, beds of the formation may sometimes be distinguished by a more or less perfect stratification or regular arrangement of the surface-gravel, indicating the former action of water. Such beds are sometimes called *beaches* and attributed to sea-shore action, although containing no evidence of this origin from marine remains or other satisfactory marks. They are also termed, with a degree of propriety, *modified drift.*

(*c.*) *Sea-border formations.*—On sea-shores, also, there are analogous deposits, situated above the height at which accumulations are now in progress. They often have the characters of the modern sea-beach, and are then rightly termed *ancient sea-beaches;* and the terrace, in such a case, about the mouths of rivers passes directly into that of the river-border formation. In other places they resemble more the shallow-water deposits of a coast. They often bear distinct evidence of their marine origin in the presence of marine shells. Such beds have been observed near Brooklyn on Long Island, where they contain shells and have a height of one hundred feet above the sea-level; at several places on the coast of New England; on the shores of Lake Champlain, at different heights, up to 393 feet above tide-level, and containing shells to a height of 325 feet; on the borders of the St. Lawrence, with abundant marine fossils; near Quebec, Montreal, and on the Ottawa, to a height between 400 and 500; and beyond to Kingston. From this point the same formations continue on, and border Lake Ontario, but they are destitute of marine remains,—the waters of the river St. Lawrence beyond having apparently prevented the farther ingress of the ocean and of marine life.

Similar beach formations, containing recent shells, occur in the Arctic regions at various places, as on Cornwallis and Beechey

Islands in Barrow Straits, where they are at different heights, to 1000 feet above the sea.

Material of the beds.—The beds consist of loose earth or loam, clay, gravel, and occasionally large stones. They may be either destitute of lamination,—a very common characteristic,—or finely laminated like the silt or clay of river-flats. They are sometimes partially consolidated, though usually little more compact than the modern alluvium. Some of the layers, especially those of clay, contain hard concretions, in which carbonate of lime is usually the concreting ingredient. The stratification, wherever observable, is horizontal or nearly so, unless disturbed by the fall or undermining of masses.

Instances occur of contortions in the clayey layers in which the sandy beds above or below do not partake. Such layers of clay, when thoroughly wet, will readily become flexed from any laterally-acting pressure when the other beds will only be compressed; and they have been known to be forced out altogether under the superincumbent pressure of a high bank.

The surface of the upper alluvial plain is often excessively pebbly or stony, because of the removal of the finer soil in which the pebbles or stones were imbedded by the winds and rains. As the beds are soft, they are readily worn away by both causes. In many regions the great plain is changed into a succession of hills and ridges by the action of the rills and streamlets set in motion by the rains, and the surface of each becomes spread over with the stones or pebbles left loose by the process.

Thickness.—The thickness of the formation, when the river is large and the valley broad, may be thousands of feet; for, besides rising above the stream, it underlies its bed, filling the valley, whatever its extent, down to the true Drift, or some other subjacent formation. If, however, solid rocks form the bed of the river, the whole thickness is open to view. All the material of the valley-alluvium belongs properly to the formation of the Champlain epoch, excepting the portion which has been worked over and brought in by the stream in making the surface of the lower terraces and the modern river-flats.

Relation to the level of the adjoining river.—There is in all cases some approximate parallelism between the upper level of the formation and that of the bed of the adjoining river, although often obscured by the wear or denudation which has taken place since it was formed. Yet through long distances there is often a gradual and regular divergence from this parallelism, in two ways.

(1.) There is usually over the continent a slight increase of height in going north.

On the coast along the southern borders of New England, as at the mouth of the Connecticut, or at New Haven, the height of the upper plain above the river is about 35 feet; at East Hartford, Ct., 36 miles north, 40 feet; at East Wind-

sor, Ct., 48 miles, 71 feet; at Long Meadow and Springfield, Mass., 62 miles, 136 feet; at Willimansett, Mass., 68 miles, 194 feet. (Hitchcock.) At Hanover, N.H., the height is about 216½ feet. (Hubbard.) Measuring from the lower river-plain in each case, these heights are—at New Haven, 30 feet; Hartford, 30; E. Windsor, 50; Springfield, 112; Willimansett, 170; Hanover, 182.

The sandy terrace between Schenectady and Albany, N.Y., and opposite the latter place on the east side of the Hudson, is 330 to 335 feet above the river. On the Genesee River east of Portage the upper level is 235 feet above the river.

On the south side of Lake Ontario the "ridge-road" terrace has an elevation of about 160 feet above the lake, or 590 above tide-level. There are similar high terraces on Lake Erie and the other lakes west. On the north shore of Lake Superior the greatest height reported is 330 feet above the lake.

But (2) where a river becomes much diminished in size towards its source, the height of the upper plain diminishes notwithstanding the increased northing, on the general principle that all small streams have small alluvial formations, whether modern or ancient.

Relation to the level of the Ocean.—In the position of the upper limit of the river-formations there is no direct relation to the level of the ocean. The beds, although horizontal and undisturbed, occur at all levels, according to the varying heights of the streams or lakes over the land. When the latter are two or three thousand feet above the ocean, the alluvial formation will have the same height, with the addition of some dozens or scores more of feet, as the case may be.

In the sea-shore formations, however, there is the same increase of height above the ocean's level to the northward as there is in the river-formations above the level of the river's bed. South of New York the height observed is seldom over 10 or 15 feet; in southern New England, 30 to 35 feet; on Lake Champlain, 468 feet; at Montreal, 470 feet above Lake St. Peter, or 450 feet above the river St. Lawrence at the place. In the Arctic regions, in Barrow's Straits they have in some places a height of 1000 feet above the sea.

At Brooklyn, Long Island, sea-shore deposits are 100 feet above the sea; at New Haven, Ct., 35 feet; at New London, Ct., 35 feet; at Sankaty Head on Nantucket, 30 feet. In Maine they occur at many places near the coast, as Portland, Cumberland, Brunswick, Thomaston, Cherryfield, Lubec, Perry, etc., at different elevations, not exceeding 200 feet; also distant from the coast, at Gardiner, Hallowell, Lewiston, Skowhegan, Clinton Falls, and Bangor. At Lewiston a starfish and various shells were found in a bed 200 feet above the ocean and 100 above the Androscoggin River; at Skowhegan the beds are 150 feet above the ocean, and at Bangor 100 feet. (C. H. Hitchcock.)

There are shell-beds at several levels and many localities along the St. Lawrence, observed by Logan, and part, as Dawson has shown, are sea-beaches and others off-shore deposits. At Montreal, at a height of 450, 420, 366, 200, 100,

above the river, or 20 feet more for each above Lake St. Peter; west of Montreal, near Kemptville, at a height of 250 feet; in Winchester, 300; in Kenyon, 270; in Lochiel, 264 and 290; at Hobbes Falls in Fitzroy, 350; at Dulham Mills, 289; in the counties of Renfrew, Lanark, Carlton, and Leeds, 425; east of Montreal, near Upton Station, 257; farther east, on the river Gouffre, near Murray Bay, 130 and 360 feet.

The 100 foot level near Montreal was apparently beneath the sea at the time, as the shells in which it abounds are not littoral species, neither are the specimens water-worn. At Beauport, near Quebec, there are thick beds of this kind, mostly made of shells, partly littoral, and situated at a height of 200 to 400 feet above the sea. The depth of water inferred for these deep-sea beds by Dawson from the species of shells is 100 to 300 feet. Dawson makes the marine formation in Canada to consist (1) of the deep-water clays just mentioned, which he calls *Leda clays*, from one of the fossils; (2) the overlying shallow-water sands and gravels, called also the *Saxicava sand*.

The more common shells of the Montreal beds are the following:—*Saxicava rugosa, Mya truncata, Tellina Groenlandica, Astarte Laurentiana, Mytilus edulis, Mya arenaria, Tellina calcarea, Natica clausa*, and *Leda Portlandica*,—the last a deep-water species. Among the Beauport species there are the following:—*Natica Groenlandica, N. Heros, Turritella erosa, Scalaria Groenlandica, Littorina palliata, Cardium Groenlandicum, Cardium Islandicum, Pecten Islandicus, Rhynchonella psittacea, Echinus granulatus*. All are cold-water species, and more like those of the open sea-shore than the kinds found at Montreal, corresponding with the fact that Montreal is 150 miles northwest of Beauport (Dawson). The same kinds are common also in the Maine beds. The species thus far discovered, with perhaps one or two exceptions, are identical with those now inhabiting the Labrador seas.

The *Capelin* (a common fish on the Labrador coast) has been found fossil on the Chaudière Lake in Canada, 183 feet above Lake St. Peter; on the Madawaska, 206 feet; at Fort Colonge Lake, 365 feet.

The facts indicate that salt waters spread over a large coast-region of Maine, and up the St. Lawrence nearly to Lake Ontario, and covered also Lake Champlain, besides several Canada lakes. This great arm of the sea, nearly 500 feet deep at Montreal and in Lake Champlain, was frequented by whales and seal: remains of both kinds have been found near Montreal, and a large part of the skeleton of a whale—*Beluga Vermontana* Thompson (fig. 840)—has been dug up on the borders of Lake Champlain, 60 feet above its level, or 150 above that of the ocean.

II. General Observations.

American Geography.—The close approximation in height between the alluvial and sea-shore formations in the same latitudes, and the parallel increase of height on going north, show that all belong to a common epoch, and have, in one sense, a common

origin. The facts prove that the continent, over at least its colder temperate latitudes, was depressed below its present level, and that this depression extended across it from the Atlantic far towards the Rocky Mountains, and existed also west of the mountains over Oregon and California.

The amount of depression was 30 feet along southern New England, as proved by the elevated beaches. It was 30 to 50 in northern Connecticut, 100 to 170 in Massachusetts, and from 170 to 200 in New Hampshire, as shown by the height of the upper river terrace on the Connecticut above the lower flats. It was 400 feet about Lake Champlain, and 450 or more in the vicinity of Montreal, as indicated by beds containing marine fossils. The upper terraces of the Great Lakes show a like depression in their vicinity, amounting to at least 330 feet on the north shore of Lake Superior. The elevated sea-beaches of the Arctic correspond to a depression there of 1000 feet in some regions. There was therefore a marked geographical change over the northern latitudes between the Glacial and Champlain epochs,—a change from a condition of *elevation*, in which the sea-border lay outside of its present limits, to one of *depression*, in which the ocean encroached again on the land, making Lake Champlain and the St. Lawrence, for a long distance, arms of the sea.

The subsidence may have affected the southern part of the United States and carried the continent there eight or ten feet below its present level. The evidence is not satisfactory on this point. On the Pacific side of the continent the subsidence amounted to some hundreds of feet. It is probable that the auriferous gravel of California was made from the pre-existing rocks and distributed over the hills and valleys during the Glacial and Champlain epochs.

Sea-beaches mark the presence of the sea in so many places about New England and Canada that we admit at once the conclusion they suggest. And, being so common to the height mentioned, we certainly have abundant reason for doubting any depression of the continent beyond this extent. Hence, the submergence in the Glacial period of 4000 or 5000 feet, required to meet the necessities of the Iceberg theory, may well be pronounced altogether improbable.

Climate.—(1.) *Temperature of the sea.*—In consequence of the depression of the continent making an extended gulf of the river St. Lawrence, the Labrador or polar current (p. 41) would have carried its waters and temperature westward beyond Montreal. As the species of shells in the elevated beaches are all such as inhabit the present coasts from the Arctic to Maine, the temperature of the waters must have been essentially the same as now. By reference to the Physiographic Chart, it will be seen that the *North Frigid* tem-

perature zone, the coldest of the ocean, descends now on the coast into the Gulf of St. Lawrence; so that the depression could only have given greater extension to the waters. The zones of oceanic temperature in the Middle Post-tertiary period approximated, therefore, to those of the present day.

(2.) *Temperature of the air.*—A cold oceanic temperature and a warm climate may be in close proximity; the chart referred to gives an example of this on the coast of Peru (see p. 43). Hence we have to look to other facts than those from oceanic species to determine the climate of the epoch. The depression of the land over the north would of itself be a cause of a warmer climate than the present (p. 45); and this inference is sustained by the life over the land. The facts on this point are stated beyond.

One of the earliest effects of the subsidence would have been the melting of the glaciers of the Glacial epoch. This would have made a vast flow of waters over the continent through all the valleys which had been in process of excavation, and it would have filled them with sand, gravel, or earth, making each, when the land had reached its lowest depression, a vast plain of alluvium through which the stream would have run in its narrow channel, except in its times of floods, when it may have spread over its whole breadth. And while the glaciers were disappearing, many a stream or lake would have existed to stratify the drift (p. 549) and cause denudation in elevated places where now there are no running waters within scores of miles.

3. TERRACE EPOCH.

The TERRACE epoch belongs in part, at least, to the age of Man, being, as has been stated on p. 535, a *transition* epoch. But the relations, both geographical and zoological, which it bears to the Post-tertiary are such that its general characteristics are most conveniently stated in this place.

Distribution and origin of the Terraces in North America.

The sea-beaches and river-flats of the Champlain epoch are at the present time *elevated* beaches and plains; and the heights of many of them are already given on pages 549–552. The time when they were raised, and became terraces along the rivers, lakes, and sea-coast, corresponds to the Terrace epoch; and during the process other parallel terraces were formed. These proofs of elevation are coextensive with the breadth of the continent, as is evident from the account of them under the Champlain epoch.

Oscillations of level have taken place in many regions at later times, and these throw some doubt over the exact amount of change in particular regions during the Terrace epoch. Yet its characteristics stand out in bold relief:—

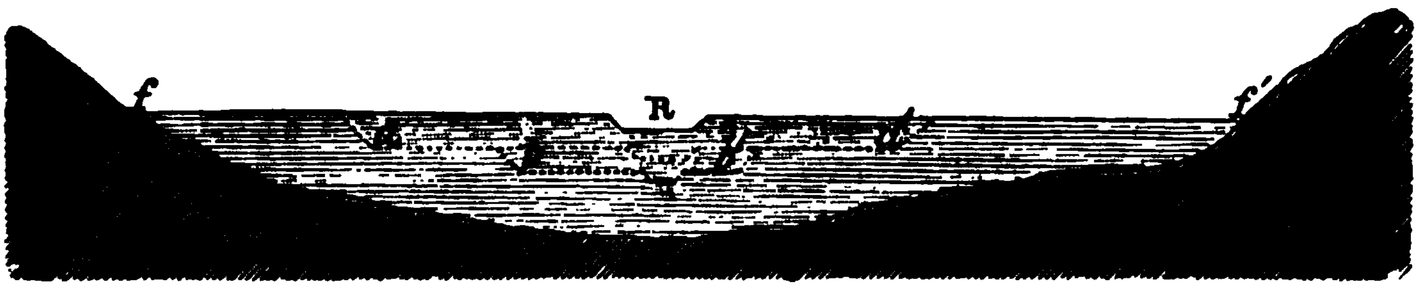
(1.) The continental extent of the area that was elevated.

(2.) The fact that there was an increase in the amount of elevation from the south to the north.

The elevated sea-beaches of the Arctic are higher than those of the St. Lawrence, and those of the St. Lawrence higher than those of southern New England; and the upper terraces of the Great Lakes higher than those south of the Ohio. The change of level was eminently *northern*, like that introducing the Champlain epoch, only different in direction,—*upward* instead of downward.

The formation of the river-terraces (fig. 830, p. 548) has been stated to be a consequence of the elevation of the land. This is illustrated in the following cuts. The condition of a river and its

Fig. 831.



Section of a valley in the Champlain epoch, with dotted lines showing the terraces of the Terrace epoch.

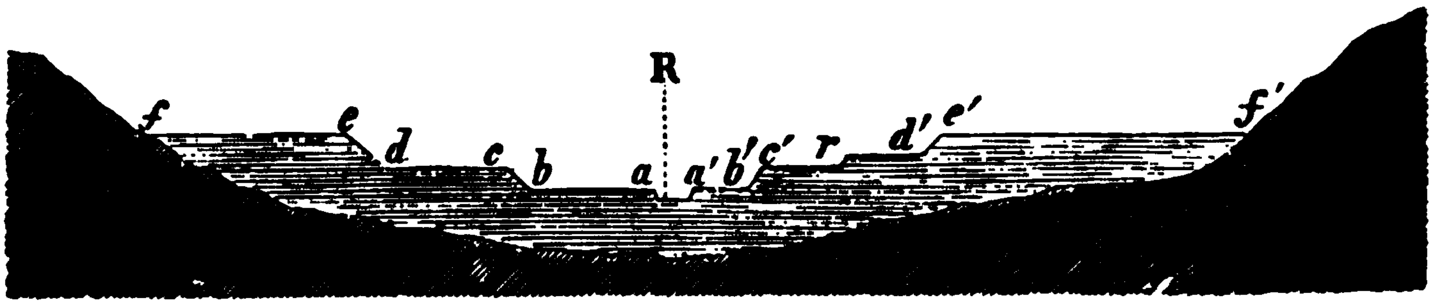
river-flat in the Champlain epoch is shown in fig. 831, in which *R* is the river-channel, in the broad river-flat *ff'*. Rivers in an open country have always both these two elements, a *channel* and a *river-flat* or *flood-plain*. The stream occupies the former during ordinary low water, but spreads over the latter during freshets. The sweeping violence of the flood determines the limits, other things being equal, and the flat surface of the flood-plain or river-flat.

If now the interior of a continent be raised, say 100 feet, while along the sea-coast it is little changed, the river will have an increased angle of slope, a quicker flow, and greater power of erosion; and it will gradually wear down its channel, if there are no rocks to prevent, until the old slope is again attained. The flood-plain will also sink at the same rate, although with more or less changed limits, owing to many causes of variation. The line *d d'* would then be the flood-plain or river-flat with its channel (below R). After another similar elevation, *b b'* might be the flood-plain and channel. In fig. 832 a section of a valley, thus terraced, is represented.

(The underlying drift, beneath the alluvium, is not shown.) It appears thus that each terrace was once part of a flood-plain of the river.

In the above explanation the terraces are supposed to correspond each to a separate period of elevation. This may be the case; and, when so, the same terrace would be traceable for great distances along the course of the larger rivers. But successive terraces may be formed in river-valleys, either (1) during a slowly-progressing elevation, or (2) in the course of the wear which may be in progress between periods of elevation; and it is often difficult to distinguish these accidental or intermediate plains from those that are distinct records of change of level. One such intermediate ter-

Fig. 832.



Section of a valley with its terraces completed.

race is shown at *r* in fig. 832. Some of the conditions producing them are the following:—(1) changes in the river-channel to one side or the other of the river-valley, altering thereby the action of the flood-waters during freshets, and causing them to commence wear according to a new outline; (2) resistance to wear in a portion of the alluvium, owing to a degree of consolidation, or to some obstacle; (3) a permanent diminution in the waters of a stream, arising from changes about its sources, or in some other way.

It is important to observe also that the same terrace may differ in height ten to fifteen feet or more; because (1) the flood-plains of rivers (the original condition of the terrace-plains) often differ much in height in different parts; (2) the rains and streamlets often wear away the soft material of the terraces, diminishing their height, and sometimes obliterating the plain altogether; (3) the winds carry off the light soil of the surface, and in the course of centuries may produce great results.

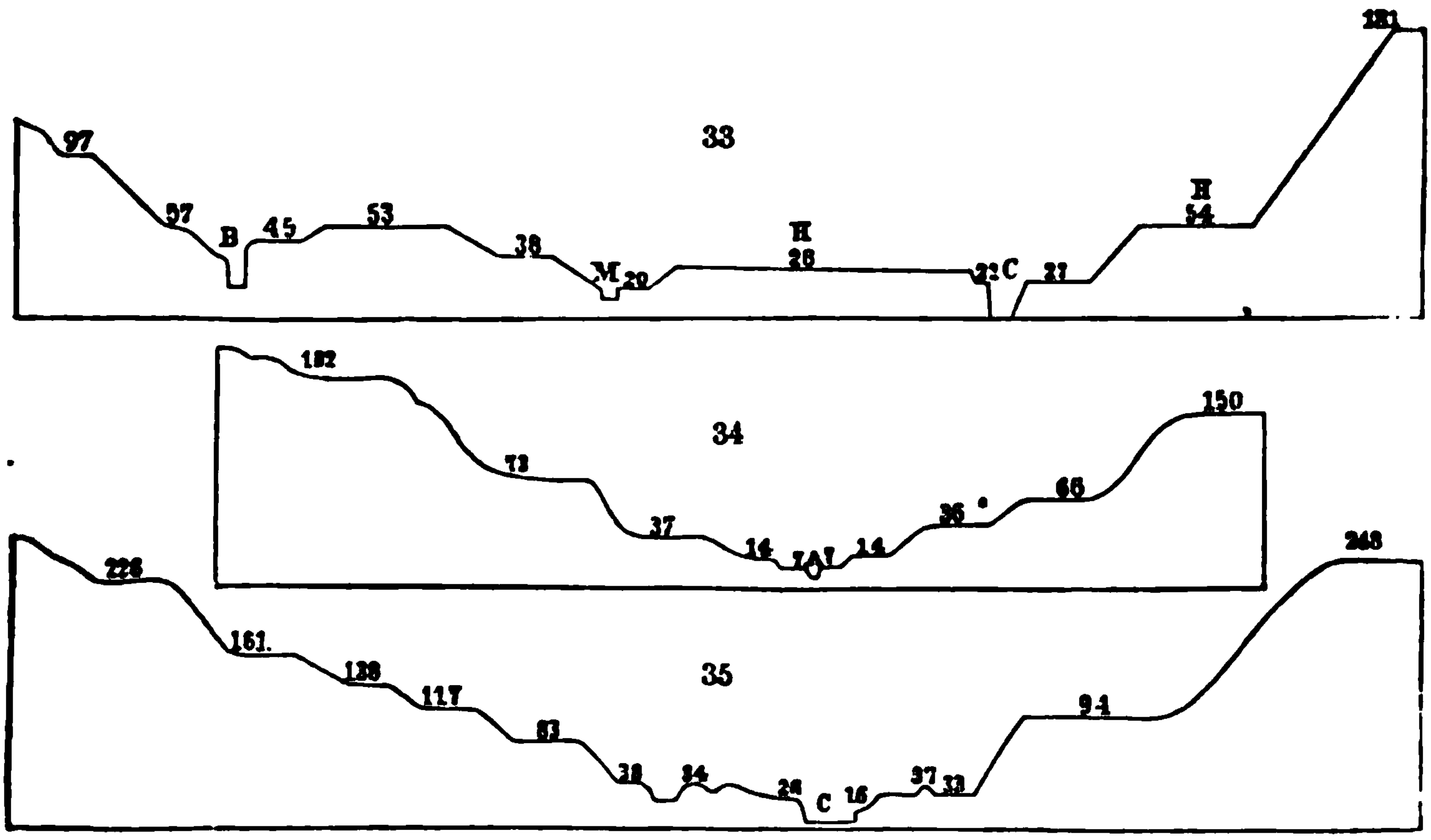
Again, the terraces of small tributaries at a distance from the river into which they flow, are lower than those of the latter, because both their floods and their eroding power are less.

Again, when there are rocks in the course of a stream, a terrace above the rocky barrier may differ in height from its counterpart

below, because the stream is unable to wear down its bed, and is more or less dammed up by the barrier.

The following figures represent terraces on rivers in New England, as figured by Hitchcock, and illustrate both the regularities and irregularities of level among them. Fig. 833 is from the vicinity of Hadley, Mass., on the Connecticut; fig. 834 from Hinsdale, N.H., on the Ashuelot River; fig. 835 from Walpole, N.H., on the Connecticut. In the last the opposite terraces of 83 and 94 feet are probably parts of one and the same level; and so also the uppermost, 226 and 243. The subordinate terraces are quite numerous on the left side, arising in part from the fact that two streams, Cold and Saxon Rivers, enter the Connecticut near by.

Figs. 833–835.



Sections of terraced valleys in New England, with the heights of the terraces in feet: 833, on the Connecticut, at Hadley; B, a brook; M, Mill River; H, Hatfield; C, Connecticut River; H, Hadley; 834, on the Ashuelot, at Hinsdale; 835, on the Connecticut, at Walpole.

Other considerations bearing on this subject, and essential to right conclusions, are presented in the chapter beyond, on rivers.

General Observations.

Among the results on the American continent of the elevations of the Terrace epoch were the following: (1) the expansion and elevation of the land bringing it nearly or quite to its present out-

line; (2) the terracing of the borders of the lakes and rivers over the middle and northern latitudes of the continent; (3) the reducing of the level of the rivers nearly to that of their present channels and flood-plains.

Champlain and Terrace Epochs in Foreign Countries.

Vast alluvial deposits subsequent in origin to the Drift of the Glacial period, and river and lake terraces, are as much a general feature of Britain and Europe as of North America; and, moreover, the phenomena are most remarkable over the more northern latitudes. But the fact that glaciers have been perpetual in Europe since the Glacial period, and the general complexity of geological movements about that corner of the Orient, make it more difficult to locate the particular cases in the special epoch to which they belong, or to separate them from the results of modern changes.

The terraces in Great Britain, and especially its northern part, Scotland, are on a grand scale. The benches of Glen Roy are an example of them. The upper terrace is 1139 feet above tide-level; the second, 1059; the third, 847 feet. This is one among many cases that might be cited. As a general thing, elevated sea-beaches occur on the coasts of regions whose interior is diversified with lake and river terraces. When the facts are thoroughly studied, and the exceptional cases traced to their true causes, there will probably be found a system of phenomena which will prove that in Europe, as in America, the Post-tertiary was a period of high-latitude oscillations; of an upward movement for the Glacial epoch; a downward—to so great a degree that the upper flats in the system were flooded—for a following epoch, the Champlain; and an upward again to the present level in subsequent time.

As an example of the peculiarities of the European continent, it may be mentioned that the great Swiss glacier which buried all Switzerland in ice probably belonged to the Terrace epoch; for the drift-stones and gravel traced to it overlie the alluvium of the country (see p. 577).

LIFE OF THE POST-TERTIARY.

It has been already stated that the plants and invertebrates (Mollusks, etc.) of the Post-tertiary are, with a rare exception, *living species*, while the Quadrupeds are *nearly all extinct*.

The Drift epoch in America has afforded no organic relics except half-fossilized wood. There is as yet no evidence of any quadrupeds

until the milder Champlain epoch had set in. In Europe there is not this exclusion of organic remains from the Drift.

Europe and Asia.—The Quadrupeds of Post-tertiary Europe are a great advance beyond those of the Tertiary period in the proportion and size of the Carnivores. Caverns in Britain and Europe were the dens of gigantic Tigers and Hyenas, while Pachyderms and Ruminants, equally gigantic compared with modern species, roamed over the continent from the Mediterranean and India to the Arctic seas. The remains are found in the earthy or stalagmitic floors of caverns; mired in ancient marshes; buried in river and lacustrine alluvium, or seashore deposits; or frozen and cased in Arctic ice.

Fig. 836.

Tooth of the Cave Bear.

The most famous of the caverns are near Kirkdale, England, twenty-five miles north-northeast of York, explored by Buckland; at Bristol, England; Kent's Cave near Torquay; Gaylenreuth in Germany.

The European caves were mostly caves of Bears (the great *Ursus spelæus*), while those of England were occupied by Hyenas (*Hyæna spelæa*), with few bears. Fig. 836 represents the canine tooth of the Cave Bear.

At Kirkdale, the Hyena bones and teeth—which belonged to at least seventy-five individuals—were mingled with remains of extinct species of Elephant, Tiger, Bear, Wolf, Fox, Hare, Weasel, Rhinoceros, Horse, Hippopotamus, Ox, and Deer,—all of which then populated Britain. The Hyenas hither dragged the dead carcasses they found, and lived on

the bones, and also the bones of fellow-Hyenas; and the bottom of the cave was covered with the fragments. Calcareous excrements were also abundant, quite similar to the excrements of the modern Hyena of south Africa (*H. crocuta*).

Some idea has been given of Britain in the age of Reptiles. The following from Owen gives a later picture of England,—England in the Post-tertiary, the last age before Man.

"Gigantic Elephants, of nearly twice the bulk of the largest individuals that now exist in Ceylon and Africa, roamed here in herds, if we may judge from the abundance of their remains. Two-horned Rhinoceroses of at least two species forced their way through the ancient forests, or wallowed in the swamps. The lakes and rivers were tenanted by Hippopotamuses as bulky and with as formidable tusks as those of Africa. Three kinds of wild Oxen, two of which were of colossal strength, and one of these maned and villous like the Bonassus, found subsistence in the plains." There were also Deer of gigantic dimensions, wild Horses and Boars, a Wild-Cat, Lynx, Leopard, a British Tiger larger than that of Bengal, and another Carnivore, as large, of the genus *Machærodus*, which, "from the great length and sharpness of its sabre-shaped canines, sometimes eight inches long, was probably the most ferocious and destructive of its peculiarly carnivorous family." "Besides these," continues Professor Owen, "troops of Hyenas, larger than the fierce *Hyæna crocuta* of south Africa, which they most resembled, crunched the bones of the carcasses relinquished by the nobler beasts of prey, and doubtless often themselves waged a war of extermination on the feebler quadrupeds."

There were also in Britain a savage Bear, larger than the Grisly Bear of the Rocky Mountains, Wolves, and various smaller animals down to Bats, Moles, Rats, and Mice.

The remains of the *Hyæna spelæa* have been found in France, Germany, and Belgium, as well as England. The great Cave Bear (*Ursus spelæus*) left its bones in the same countries; and the cavern at Gaylenreuth is said to have afforded fragments of at least 800 individuals.

The Elephant of the region was the *Elephas primigenius*, or Mammoth. It lived in herds over England, and extended its wanderings across the Siberian plains to the Arctic Ocean and Behrings Straits, and beyond into North America; but it seems not to have gone far south of the parallel of 40°. It is stated by Woodward that over 2000 grinders were dredged up by the fishermen of the little village of Happisburgh in the space of thirteen years; and other localities in and about England are also noted.

This ancient Elephant was over twice the weight of the largest modern species, and nearly a third taller. One of the tusks found measures 12½ feet in length; it was curved nearly into a circle, though a little obliquely. Moreover, the body was covered with a reddish wool and long black hair. The remains are exceedingly abundant at Eschscholtz Bay, near Behrings Straits, where the ivory

tusks are gathered for exportation. At the mouth of the Lena one of these animals was found, at the beginning of this century, frozen and encased in ice. It measured 16 feet 4 inches in length to the extremity of the tail, and 9 feet 4 inches in height. It retained the wool on its hide, and was so perfectly preserved that the flesh was eaten by the dogs.

The Elephant has in all twenty-four teeth (grinders), but usually only eight at a time, two in each side of each jaw. The new teeth come up behind and push the others forward and out; and thus there is a succession until the last has grown.

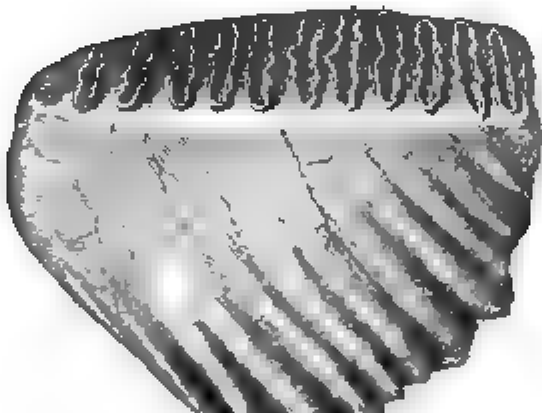
The Rhinoceros of Post-tertiary Europe is the *R. tichorinus*. It spread from England to Siberia. A frozen specimen in Siberia was found near Wilui in 1772. It had a length of 11½ feet, and appears to have been a hairy species.

The Irish Elk (*Megaceros Hibernicus*) is another of the gigantic animals of the Post-tertiary. Specimens have been found in marl beneath the peat of swamps in Ireland and England, and fragments in the bone-caverns. The height to the summit of the antlers was 10 to 11 feet, and the span of the antlers was 8 feet, or twice that of the American Moose.

America.—America in the Post-tertiary period was inferior to Europe in the number of its Carnivores, but presents the gigantic feature of the life of the time in its species.

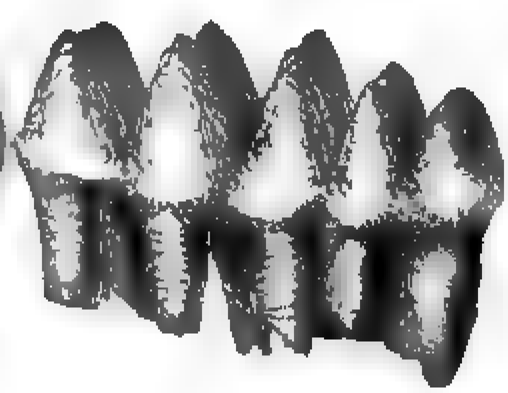
In *North America* the remains have been found in the ancient and surface alluvium, but not yet in the unstratified drift. The species

Fig. 837.



Elephas Americanus.

Fig. 838.



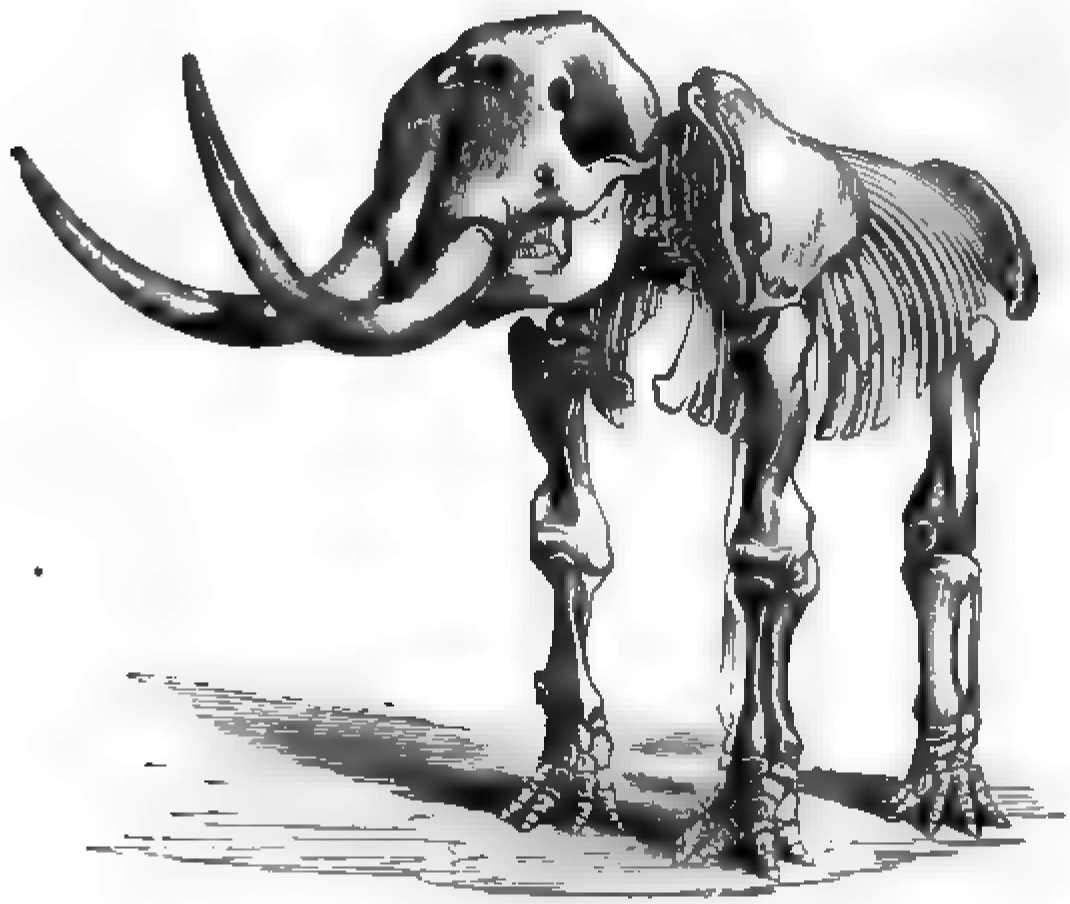
Mastodon giganteus.

included an *Elephant* (*E. Americanus*, fig. 837) as large as the European; a *Mastodon* (*M. giganteus*, fig. 839) of still greater magni-

tude; *Horses* much larger than the moderns; species of *Ox*, *Bison*, *Tapir*, gigantic *Beavers*, species of *Dicotyles* (related to the Hog); also animals of the Sloth tribe, of the genera *Megatherium*, *Mylodon*, and *Megalonyx*, of great size compared with those now living. Among Carnivores there were a *Bear*, a *Lion*, and a *Raccoon*; and these were probably not cavern species, as no bone-caverns of these animals have been found, although caverns are common in the country.

The American Elephant ranged from Georgia, Texas, and Mexico

Fig. 839.



Skeleton of Mastodon giganteus (M. Ohioticus).

on the south to Canada on the north, and to Oregon and California on the west. A tooth was found in ancient alluvium near the Colorado in 114½° W. and 35¾° N. (Newberry). Parts of one skeleton were dug up in Vermont at Mount Holly, 1415 feet above tide-level. The species appears to have been most abundant to the south, in the Mississippi valley, it preferring a warmer climate than that of the *E. primigenius*. Fig. 837 represents one of the teeth found in the State of Ohio.

The Elephant of northern North America in the British possessions is supposed to have been the Siberian species.

Mastodon remains are met with most abundantly over the northern half of the United States, though occurring also in the Carolinas, Mississippi, Arkansas, and Texas. They are found also in Canada and Nova Scotia. Five perfect skeletons have been dug up, three from the fresh-water marshes of Orange co., N.Y.,—where they appear to have been mired,—one from a morass in New Jersey, and another on the banks of the Missouri. Great numbers of bones have been found at Big Bone Lick in Kentucky. In New England a few bones have been found near New Britain and Cheshire in Connecticut. The finest skeleton in any collection is that set up by Dr. Warren at Boston (fig. 839), taken from a marsh near Newburgh. Its height is 11 feet; the length to the base of the tail, 17 feet; the tusks 12 feet long,—2¼ feet being inserted in the sockets. When alive, the height must have been 12 or 13 feet, and the length, adding 7 feet for the tusks, 24 or 25 feet. Remains of the undigested food were found between his ribs, showing that he lived in part on spruce and fir trees. One of the teeth of an American Mastodon is shown in fig. 838.

Castoroides Ohioensis is the name of the great Rodent related to the Beaver (*Castor Canadensis*). The Beaver is an animal about three feet long, exclusive of the tail; and the *Castoroides* was almost or quite five feet. Its bones have been found in the States of New York, Ohio, Mississippi (near Natchez), etc.

Bison latifrons Leidy, is the name of a Post-tertiary Bison or Buffalo, much larger than the existing Buffalo, which lived in the Mississippi valley. There were also species of Ox related to the Musk-Ox, called *Bootherium* by Leidy.

A stag, *Cervus Americanus* Leidy, whose bones occur at Natchez, exceeded in size the Irish Elk. A Horse from the same locality was also gigantic,—a fit cotemporary, as Leidy observes, of the Mastodon and Elephant.

The American Post-tertiary Lion, *Felis atrox* Leidy, was about as large as that of Britain. Only a single jaw-bone has been found at the Natchez bone-locality, where occur remains of species of Bear, Horse, Elephant, Mastodon, Castoroides, Megalonyx, and Mylodon.

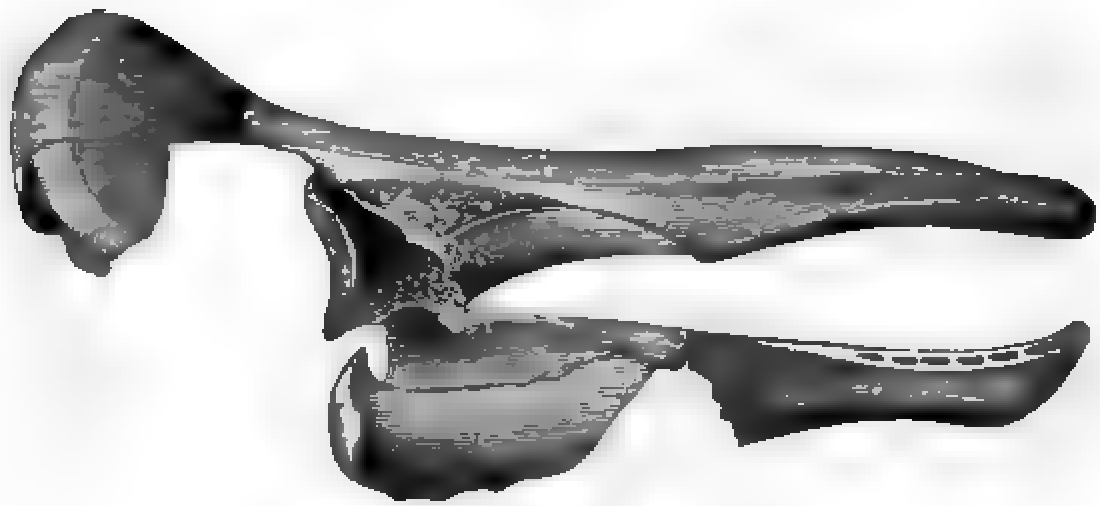
The animals of the Sloth tribe are South American in type. They are at the present time mostly confined to South America, as they were also in the Post-tertiary.

The Cetacean or *Whale*, whose remains were found on the borders of Lake Champlain, is supposed to have been about fourteen feet in length. Fig. 840 represents the bones of the head, reduced to one-sixth the natural size. The species, *Beluga Vermontana* Thompson, closely resembles the *B. Leucas*, or small northern White Whale.

In *South America* over one hundred species of extinct Post-tertiary

quadrupeds have been made out. The bones occur in great numbers over the prairies or pampas of La Plata, and in the caverns of Brazil; and they include some thirty species of Rodents (*Squirrels*, *Beavers*, etc.), species of *Horse*, *Tapir*, *Lama*, *Stag*, a *Mastodon* different

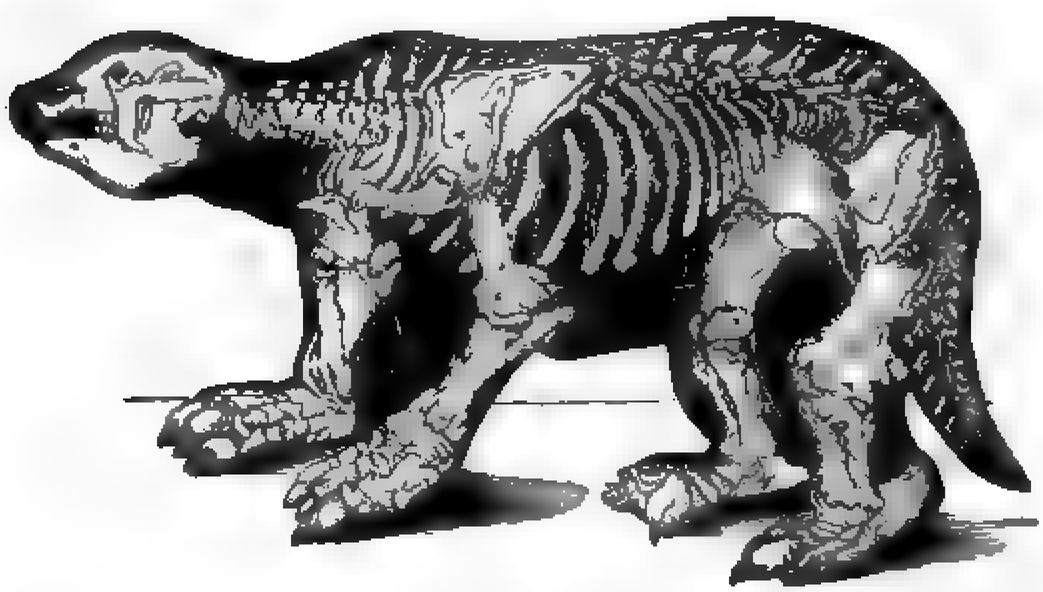
Fig. 840.



Beluga Vermontana (× 1/8).

from the North American, *Wolves* and half a dozen panther-like beasts which occupied the caverns of Brazil, *Ant-eaters*, twelve or

Fig. 841.



Megatherium Cuvieri (× 1/5).

fourteen species related in tribe to the *Megatherium* (Sloth tribe), and a dozen or more related to the *Armadillo*. They number more

species than now exist in that part of the continent, and far larger species.

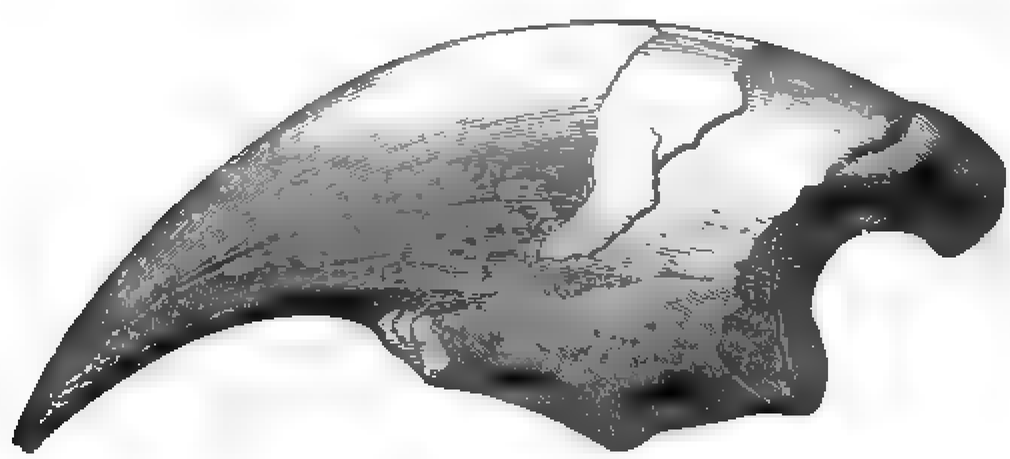
The Edentates—including the Sloth, Armadillo, and allied species—were the most remarkable. The animals of this order are stupid in aspect and lazy in movement and attitude.

The *Megatherium* (fig. 841) exceeded in size the largest Rhinoceros. The length of a skeleton in the British Museum is 18 feet. Its massy limbs were more like columns for support than organs of motion. The femur was three times as thick as an elephant's; the massive tibia and fibula were soldered together; the huge tail was like another hind leg, making a tripod to support the heavy carcass when it raised and wielded its great arms; and the hands terminating the arms were about a yard long, and ended in long claws. The teeth had a grinding surface of triangular ridges, well fitted for powerful mastication.

A species of *Megatherium* has been found in Georgia at Skiddaway Island, different from that of the Pampas.

Megalonyx is another genus of these large Sloth-like animals. Remains of species occur over the Pampas to the Straits of Ma-

Fig. 842.



Claw of Megalonyx Jeffersonii.

gellan; but the first species known was found in Virginia, in Green-Brier co., and named by Jefferson in allusion to its large claws (fig. 842). Its bones have also been found at Big Bone Lick and elsewhere.

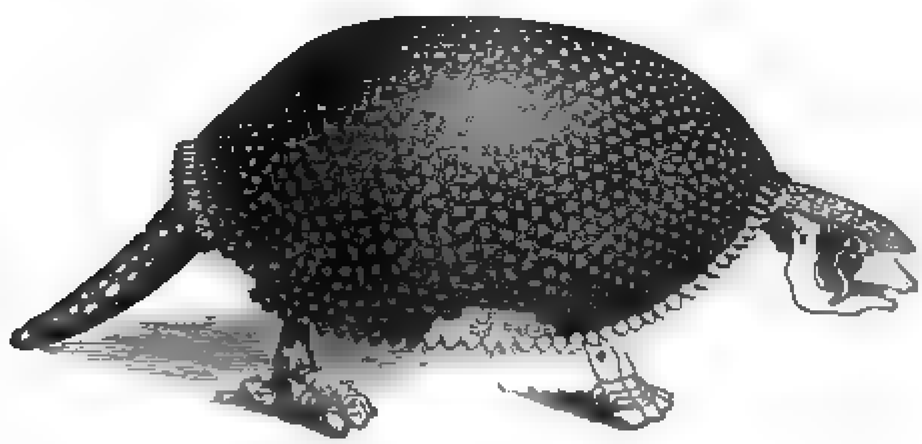
Mylodon is a third genus, and three species have been described,—two from South and one from North America. The skeleton of one, *M. robustus*, is 11 feet in length; and the animal was therefore much larger than the western Buffalo.

The North American, *M. Harlani*, has been found in Kentucky, in Benton co., Mo., and in Oregon.

A fourth allied genus is *Scelidotherium*, of which seven species have been made out,—one as large as the Megalonyx, and others but little smaller.

Of the Armadillo (or Dasypus) group the genus *Glyptodon* (fig. 843) contained several gigantic species. These animals had a shell something like a turtle. In the *G. clavipes* the length of the shell, measuring along the curve, was five feet, and the total length of the animal to the extremity of the tail, nine feet. The genus *Chlamydotherium* included other mail-clad species, one of which was as large

Fig. 843.



Glyptodon clavipes (× 1/30).

as a Rhinoceros; and the genus *Pachytherium*, others, of the size of an Ox.

Such were the characteristic animals of Post-tertiary South America. The largest Edentates of the existing period are but three or four feet in length. The Post-tertiary *Megatherium* probably exceeded more than *one-hundred fold* the bulk of any living Edentate.

Australia.—In Australia the living species are almost exclusively Marsupials. They were Marsupials also in the Post-tertiary period, but of different species; and, as on the other continents, the moderns are dwarfs by the side of the ancient tribes.

The Post-tertiary *Diprotodon* was as large as a Hippopotamus, and somewhat similar in habits. The skull alone is three feet long.

Viewing the globe as a whole, in this Post-tertiary period, we observe,—

1. The gigantic size as well as large numbers of the species,—the Elephants, Lions, Bears, and Hyenas of the Orient far larger than any modern species; so also the Horse, Elephant, Mastodon, Bea-

vers, and Lion of North America; the Megatheria and other Edentates of South America; the Diprotodon and other Marsupials in Australia.

2. The characteristic species of each continent were mainly of the same type that now characterizes it. Both in the Post-tertiary period and modern time the Orient is strikingly the continent of Carnivores; North America, of Herbivores; South America, of Edentates; Australia, of Marsupials.

With the close of the Post-tertiary far the larger part of these species became extinct. The destruction did not extend, as has been before stated, to the Mollusks and other Invertebrates,—for the same species are all or nearly all now living.

GENERAL OBSERVATIONS ON THE POST-TERTIARY.

Climate.—The hairy covering of the Elephant and Rhinoceros of Siberia shows that the climate of the Post-tertiary in those regions was not tropical. Still the several species of British and European Mammals, of Rhinoceros, Hippopotamus, Elephant, Lion, Tiger, Hyena, etc., are so closely those of warm climates that it is a safe conclusion—the only safe one—that Britain and a large part of Europe were within the warm-temperate zone. It is evident also that northern Siberia was at least not colder than Lapland, whose annual mean temperature along its northern limit, according to Dove's charts, is now 27½° F., January mean 5° F., and July mean 50° F., while the corresponding quantities for northern Siberia, near the mouths of the Lena, are at the present time 5° F., —40° F., and 50° F. The great quantities of Elephant remains at numerous points near the Arctic Ocean show that the region was the living-place of the animals, and not one frequented by occasional herds in the very short Siberian summer. This is further proved by the existence, at many places in the Arctic, of the remains of forest-trees, buried in deposits of the Age of the old Elephant. The required climate would have resulted from the Champlain subsidence (p. 554).

The last or Terrace epoch—in which the continents were raised nearly to their present level—again cooled down the earth, and ended in introducing approximately the existing climates of the globe; and the extermination of the Cave beasts of Europe and other Post-tertiary species may have been coincident with this great climatal change.

Remarks on the *Geography* of the period are included under the General Observations on the Cenozoic.

GENERAL OBSERVATIONS ON THE CENOZOIC.

1. **Time-ratios.**—Using the same kind of data as on pp. 386 and 493 for determining the relative lengths of the ages and periods, we have for the Tertiary period the maximum thickness of the Eocene beds of Europe about 3000 feet, part of which is limestone, and for the Miocene and Pliocene 7000 to 8000 (in the *Molasse* of Switzerland). It is therefore probable that the Tertiary period was about half as long as the whole Mesozoic (p. 493).

The data for the Post-tertiary are too uncertain for a satisfactory estimate. The lapse of time during the period is more marked in the extent of the valleys made than in the thickness of the rock deposits. The latter are small, because apparently the earth's surface was undergoing much smaller oscillations in this last end of its history than in earlier times. From the extent of valleys over the world, both fiords and land gorges, whose excavation was accomplished in the Post-tertiary, it is safe to infer that this period was at least half as long as the Tertiary.

Adopting these conclusions, the ratios for the Palæozoic, Mesozoic, and the two periods of the Cenozoic will be 14 : 4 : 2 : 1. If D'Orbigny's statements of the thickness of the European Cretaceous (p. 493) are right, these ratios for the Palæozoic, Mesozoic, and Cenozoic are nearly 4 : 2 : 1.

2. **Geography.**—The geographical progress of the Tertiary and Post-tertiary periods took place in different directions.

A. *Tertiary period.*—In the Tertiary, there was (1) the finishing of the rocky substratum of the continents; (2) the expansion of the continental areas to their full limits, or their permanent recovery from the waters of the ocean; (3) the elevation of many of the great mountains of the globe, or considerable portions of them, through a large part of their height, as the Alps, Pyrenees, Apennines, Himalayas, Andes, Rocky Mountains, the loftiest chains of the globe,—a result not finally completed until the latter part of the Tertiary.

In North America there occurred a small extension of the continent on the Atlantic and Gulf borders; a vast increase west of the Mississippi; a small rising of the land on the east and south, an elevation of 6000 to 7000 feet in the Rocky Mountains (nearly the whole height of the mass) and 2000 feet or more on the Pacific border.

The system of progress during the Tertiary was in each respect a continuation of that which began with the Azoic. In North America it was enlargement and elevation especially to the south-

east, south, and southwest, from the original dry land of the Azoic (p. 136).

The mass of the earth above the ocean's level was increased two or three fold between the beginning and end of the Tertiary period.

B. *Post-tertiary period.*—In the Post-tertiary, the great events, in America at least, were (1) the excavation of valleys over the lifted mountains and plains, and the shaping of the lofty summits; (2) the distribution of earth and gravel, covering and levelling the rugged surface of the earth, laying the foundation of prairies, and filling the broad valleys with alluvium; (3) the finishing of the valleys and lake-borders with a series of plains or terraces, and the extension of flats along the sea,—a work completed in the age of Man.

The excavation of valleys by running water began with the first appearance of dry land, and increased with its extent. But the greatest augmentation took place after the lofty mountains had risen in the course of the Tertiary period. The great gorges and cañons over a large part of the Rocky Mountains below a level of 6000 or 7000 feet, and most of the deep channels occupied by rivers in other regions, then had their beginning.

The cañon of the Colorado, between 111° and 115° W., is one of these gorges; and though possibly earlier in its commencement than the Tertiary period, it could have made little progress before the elevation of the mountains after the Cretaceous; for the present height of the plateau is but 6000 to 7000 feet. According to Newberry, the cañon is 300 miles long, and has walls of rock 3000 to 6000 feet high. These walls are sections of nearly horizontal strata, ranging, for the principal part of their extent, from the granite to the top of the Carboniferous, and higher up the stream to the top of the Cretaceous; and the whole bears undoubted evidence, according to Newberry, that it was made by running water. The granite has been excavated in some places to a depth of nearly 1000 feet; above this there are 2000 to 2500 feet of Palæozoic sandstones, shales, and limestones, 1000 feet of probably Subcarboniferous limestone, and 1200 feet of Carboniferous sandstones and limestone. A view of one part of the gorge is given in fig. 940, furnished the author by Newberry; and another of the side cañons, in fig. 941, from the Report of Lieut. Ives, the commander of the Colorado Exploring Expedition, of which Dr. Newberry was geologist.

There were great oscillations of level in the Post-tertiary as well as Tertiary; but (1) the Post-tertiary were mainly *high-latitude oscillations*, being most prominent over the colder latitudes of the globe, the cold-temperate and Arctic; (2) they were movements of the broad areas of the continents; (3) they brought no mountain-ranges into existence.

According to the view presented in the preceding pages, there was an upward oscillation in the Glacial epoch, a downward in the Champlain epoch, and an upward of moderate extent in the Terrace epoch. It submerged the region about Montreal and the Ottawa,

so that marine shell deposits were there formed,—an event which had not happened since the Lower Helderberg period in the Silurian age (p. 228).

The course of the movements was, therefore, diverse from that of earlier time, and their results were also widely different.

A cause of this transfer of the area of oscillation to the high latitudes may be this: that the accumulation of the successive formations over the temperate and tropical zones, and the elevation of the lofty mountains of the globe across the same regions, together with the metamorphism of part of the rocks, had so weighted, ribbed, and stiffened the crust in these parts that it was less yielding to any oscillating force than that of the regions more to the north, which till now had been the comparatively stable area. The series of rocks has less thickness and completeness in the higher latitudes than in the middle and lower, and the mountains less height.

During the Post-tertiary *some of the most prominent dynamical agencies on the globe were intensified vastly beyond their former power*:—

(1.) Owing to the completion of the great mountain-chains and the expansion of the continents, the heights for condensing moisture and the extent of slope for its accumulation into rivers had augmented many fold. Moreover, through the union of lands before separated by seas into one continental area, the rivers draining immense regions were for the first time united into a common trunk. The Post-tertiary was therefore eminently *the era of the first grand display of completed river-systems*,—of the first Amazon, Mississippi, Ganges, Indus, Nile, etc.

(2.) The elevation of the mountains to snowy altitudes introduced rivers of ice, or *glaciers*, among dynamical agencies, or gave them vastly increased extension.

(3.) The increase of cold, and the existence finally of true frigid zones, due partly, at least, to an increase of polar lands after the close of the Cretaceous period and through the Tertiary, added to the extent of glaciers, rendering them possible in regions where otherwise they could not have existed.

(4.) The cause last mentioned also gave origin to *icebergs*.

Great rivers, glaciers, and icebergs were especially characteristic forces of the Post-tertiary; and the ice accomplished what was impossible for the ocean. In no other period of geological history have so large masses of stone been moved over the earth's surface as in the Glacial and later epochs.

These Post-tertiary agencies were active everywhere over the continents, putting the finishing-strokes to the nearly completed globe. There was a development of beauty as well as utility in all

these later movements. Those conditions and special surface-details were developed that were most essential to the pastoral, agricultural, and intellectual pursuits which were to commence with the next age.

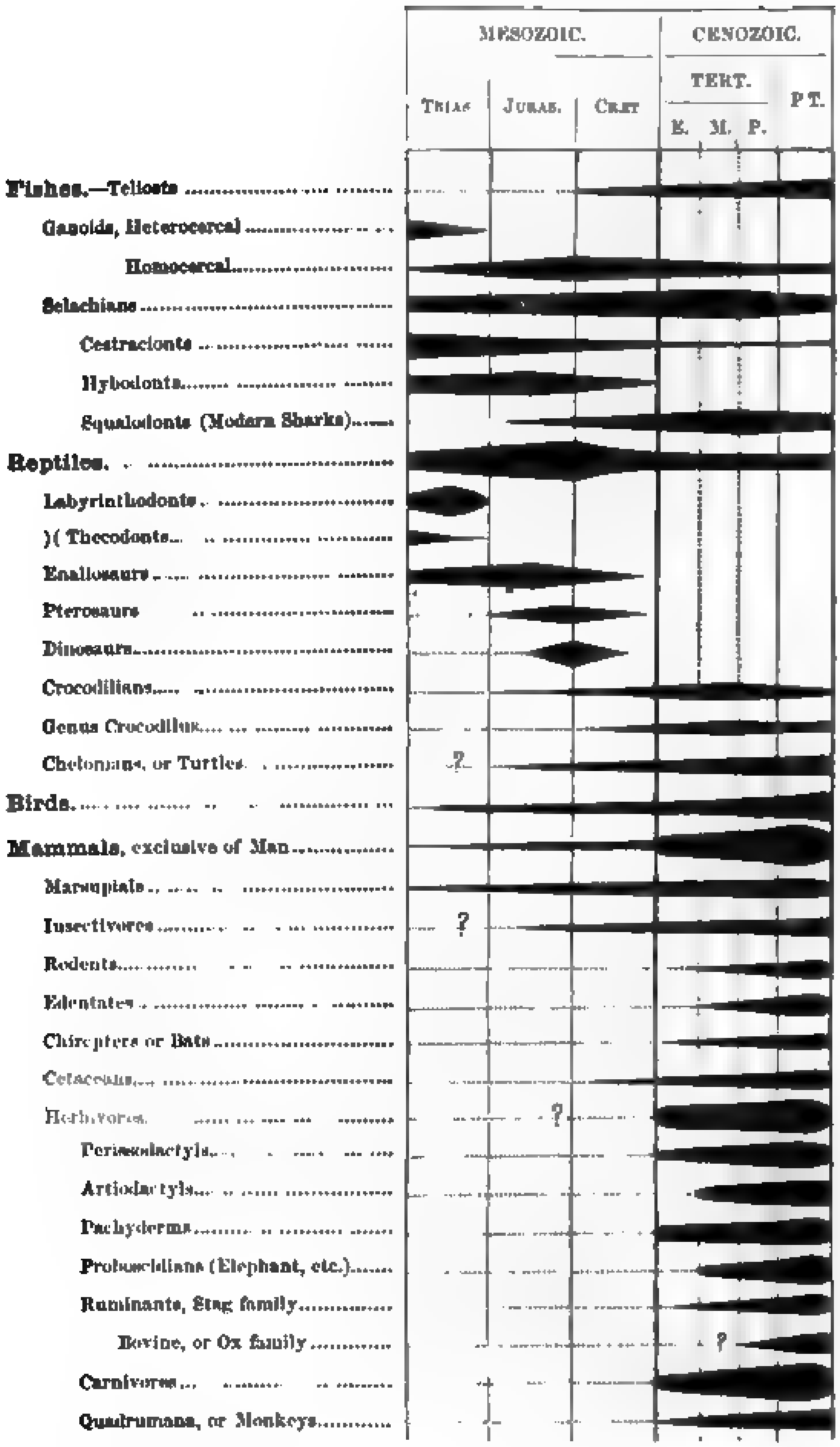
3. **Life.**—*Grand characteristic of the Cenozoic.*—The prominent fact in the life of Cenozoic time is the expansion and culmination of the type of Mammals. This culmination took place in the Post-tertiary period, whose Carnivores, Herbivores, Edentates, and Marsupials far exceeded in number and size those of the present age. It was the great feature not of one continent alone, but of all the continents, and on each under its own peculiar type of Mammalian life. The age of Mammals thus stands out prominently among the ages, strongly marked in its grand distinguishing characteristic.

The Cenozoic was also the time of culmination of the modern tribe of Sharks or Squalodonts, and of the Crocodiles and Turtles among Reptiles.

Range of Vertebrate types.—The following table presents to the eye the range of the more common Vertebrate types through the Mesozoic and Cenozoic, showing those which began in the Palæozoic, those which have their commencement, culmination, and end within these eras, and those which continue into the age of Man. The widths of the columns for the several periods correspond to the time-ratios as deduced on pp. 493, 568. But they are relatively larger than in the table for the Palæozoic on p. 400 (2⅔ds larger),—the column for the Mesozoic being *two-thirds* as wide as that for the Palæozoic, when the time-ratios deduced would require it to be *one-fourth.* This enlargement was given the columns to render the details more distinct. The symbol)(signifies having biconcave vertebræ. Under Tertiary, the letters E., M., P., stand for Eocene, Miocene, Pliocene; and P. T. for Post-tertiary.

While the genera *Bos, Bison,* and others of the Ox group probably commenced in the Pliocene, the Antelope group first appeared in the early Miocene. Among Carnivores, the Bear family commenced in the earliest Eocene; the Dog family in the middle Eocene, or Parisian group; the Cat family (*Felis,* etc.) in the later Eocene, though possibly in the middle.

In the table the interrogation-mark opposite *Herbivores,* in the column of the Jurassic period, is inserted on the authority of Owen, who questions whether the *Stereognathus* of the Purbeck beds (p. 462) may not be a "diminutive Ungulate."


MESOZOIC.
CENOZOIC.
TERT.
TRIAS.
JURAS.
CRET.
E. M. P.
P T.
Fishes.—Telleosts
Ganoids, Heterocercal
Homocercal
Selachians
Cestracionts
Hybodonts
Squalodonts (Modern Sharks)
Reptiles.
Labyrinthodonts
)(Thecodonts
Enaliosaurs
Pterosaurs
Dinosaurs
Crocodilians
Genus Crocodilus
Chelonians, or Turtles
?
Birds.
Mammals, exclusive of Man
Marsupials
Insectivores
?
Rodents
Edentates
Chiroptera or Bats
Cetaceans
Herbivores
?
Perissodactyls
Artiodactyls
Pachyderms
Proboscidians (Elephant, etc.)
Ruminants, Stag family
Bovine, or Ox family
?
Carnivores
Quadrumana, or Monkeys

V. ERA OF MIND.—AGE OF MAN.

In the preceding chapters the progress of the vegetable and animal tribes has been followed through the three grand divisions of geological time,—the Palæozoic, Mesozoic, and Cenozoic. In the latter part of the last era the animal kingdom, apart from Man, culminated; for the system then reached the highest grade of development presented by the merely animal type, and brute passion had its fullest display. In the era now opening, the animal element is no longer dominant, but Mind in the possession of a being at the head of the kingdoms of life; and the era bears the impress of its exalted characteristic even in the smaller size of its beasts of prey. At the same time, the ennobled animal structure rises to its highest perfection; for the Vertebrate type, which began during the Palæozoic in the prone or horizontal fish, finally becomes erect in Man, completing, as Agassiz has observed, the possible changes in the series to its last term.

But, beyond this, in Man the fore-limbs are not organs of locomotion, as they are in *all* other Mammals: they have passed from the *locomotive* to the *cephalic* series, being made to subserve the purposes of the head. This transfer is in accordance with a grand law in nature (explained in the note, § 5, p. 593) which is at the basis of grade and development. The intellectual character of Man, sometimes thought too intangible to be regarded by the zoological systematist, is thus expressed in his material structure. Man is therefore not one of the *Primates* alongside of the Monkeys: he stands alone,—the ARCHON of Mammals (p. 422).

In order to a correct apprehension of the distinctions and eminence of the era of Mind, a few of the attributes of Man are here enumerated.

Man was the first being that was not finished on reaching adult growth, but was provided with powers for indefinite expansion, a will for a life of work, and boundless aspirations to lead to endless improvement. He was the first being capable of an intelligent survey of nature and comprehension of her laws; the first capable of augmenting his strength by bending nature to his service, rendering thereby a weak body stronger than all possible animal force; the first capable of deriving happiness from beauty, truth, and goodness; of apprehending eternal right; of looking from the finite

towards the infinite, and communing with God his Maker. Made in the image of God, surely he is immeasurably beyond the brute, although it share with him the attribute of reason.

The supremacy of the animal in nature, which had continued until now, here yields, therefore, to the supremacy of the spiritual. As the body, through its development and adaptations, is made for the service and education of the soul that is slowly maturing in connection with it, so with the system of the world, as regards both its inorganic and organic departments, there was reference, throughout its history no less than in its final adjustments, to man, the last, the highest, the spiritual creation. And the earth subserves her chief purpose in nurturing this new creation for a still more exalted stage, that of spiritual existence.

I. Rocks: kinds and distribution.

The following are the formations of the age of Man:—

1. Of mechanical origin.—(*a.*) *Marine.*—The extended flats which border many coasts, as from Long Island to Texas, and beyond, and which are now gradually widening the area of the continents; and deltas, which are similar in general character, but are formed about the mouths of rivers.—Sea-beaches.—Sand-drifts or dunes in the vicinity of the ocean. (*b.*) *Continental.*—Alluvium of the lower river-flats; and, in case a region has undergone elevation during the age, that at higher levels.—Alluvium along the shores of lakes; and, where, through the modern opening of barriers or other cause, the waters have diminished their height, deposits above the lower plain. About large lakes, different formations analogous in every respect to the *Marine* above mentioned, except in having no marine relics.—Glacier drift or boulders and gravel, similar to that of the true Glacial epoch, though of more local distribution.

2. Of organic origin.—(*a.*) *Marine.*—Coral reefs, often of vast extent.—Shell deposits. (*b.*) *Continental.*—Peat beds, or swamp formations of vegetable character, consisting largely of growing moss in temperate and colder climates, and of diminutive turf-making flowering plants in Alpine and Arctic regions.—Shell beds or shell marl.—Siliceous infusorial deposits.

3. Of chemical origin.—Calcareous deposits called *Travertine*, derived from calcareous waters, in some cases scores of feet in thickness.—Stalactites and Stalagmites of similar form and origin in caverns.—Bog deposits of ore called *Bog ore.*

4. Of igneous origin.—Lavas and tufas of volcanic regions.

The formations here enumerated, whether along lakes, rivers, or sea-coasts, are usually underlaid by Post-tertiary beds of similar character, situated at varying depths below, often but a few feet, sometimes hundreds of feet; and the modern and Post-tertiary deposits are so closely alike that the limits of the two cannot be easily made out. The difficulty is the greater because the shells of the Post-tertiary were all of species now living. In many cases deposits are proved to belong to the age of Man by containing relics of the peculiar species of the age, as explained beyond.

The agency of air, fresh and marine waters, heat and life, in giving origin to these deposits, might be here considered. But these topics are discussed under Dynamical Geology; and to that part of the work the reader is referred.

II. Life.

The approximate number of living species of Plants is 100,000. The number of species of Animals of the sub-kingdom of Radiates is about 10,000; of Mollusks, 20,000; of Articulates, 300,000; of Vertebrates, 21,000; making a total in the Animal kingdom of about 350,000. Of existing Vertebrates the number of species of Fishes is about 10,000; of Reptiles, 2000; of Birds, 7000; of Mammals, 2000 = 21,000.

The increase during the Tertiary period in the extent of dry land and rivers, the height and number of mountains, and the diversities of the zones of climate, augmented greatly the variety of geographical conditions over the globe to which life could be accommodated. This is especially true of the land; but only in a limited degree for the ocean, which has smaller extremes of temperature than the land, and is less affected by its changes of level.

The terrestrial life of the globe should therefore, on this principle, have undergone a vast increase in the course of the later Tertiary and the period of the Post-tertiary, especially in the classes of Insects, Birds, and Mammals, and the tribes of fresh-water Fishes. Reptiles should have undergone less increase, for the species belong mainly to the warmer climates, and this type had already culminated and was on the decline.

Insects and Birds appear to have had their times of culmination in the age of Man, while Mammals, gigantic and ferocious, especially in their larger species, passed their climax in the period next preceding, and disappeared as the age of Man began. Most species of plants and animals have their parasitic insects; and an augmenta-

tion of the numbers of the former was consequently but providing for the appearance of the latter.

Invertebrates.—As to the time of the first appearance of existing Mollusks, it is known only that 15 to 25 per cent. of Miocene species of marine shells are identical with species now living; 40 to 90 per cent. of Pliocene; and all of the Post-tertiary species. This does not necessarily imply that all the species of Mollusks alive now were alive throughout the Post-tertiary; for out of the 16,000 living species only a few hundreds have yet been found in the beds of that period. Future discovery will undoubtedly add much to the number.

Among Articulates, less than 100 living species from Post-tertiary deposits are known out of the 300,000 now in existence. The two tribes latest in appearance among fossil Insects, and rarest even to the last, are that of the Lepidopters, the tribe of beauty, and that of the Hymenopters, the tribe of utility, highest instincts, and superior rank. The species of these tribes are less likely to become fossilized than those that frequent wet places, where depositions of silt might be in progress.

Vertebrates.—Very few Fishes, Reptiles, or Birds of the present era are yet known, from any discovery of fossils, to have existed in the Post-tertiary. The species have thus far been but little searched for.

Among Mammals, remains of nearly all the species of modern Europe have been found in beds containing some of the extinct Post-tertiary. The number includes the Hare, Rabbit, Beaver, common Rat and Mouse, the Marten, Wild-Cat, Dog, Fox, Stag, Roebuck, Reindeer, Aurochs, Hog, Horse, and the Glutton and Polar Bear of northern latitudes, besides many others; and probably all existing species were then distributed much as they are now over Europe. Moreover, in Sicily and Malta remains of some African Mammals have been found.

Some of the species may date from the early Post-tertiary; but the majority apparently from the Terrace or transition epoch. Their remains are found in caverns and alluvial beds, associated with bones of the Elephant (*E. primigenius*), Rhinoceros (*R. tichorinus*), and Irish Elk (*Megaceros Hibernicus*), and occasionally with those of the Hyena and Cave Bear. In some cases they have probably been mixed by more modern alluvial action; but in others they lie as they were originally buried. The alluvial beds in England, France, and Switzerland are more recent than the old Glacial drift, the latter being observed in several places as an inferior deposit.

It follows, therefore, not only that some of the large Mammals continued on beyond the time of their meridian nearly or quite through the Terrace epoch, but also that the modern tribes came into existence before their extinction. The progressing Terrace epoch was bringing about the cooler climate required for the modern species; and this change of climate was also causing the disappearance of the tribes of the older era.

The time of greatest expansion of the Post-tertiary races was probably in the Champlain epoch, when they would have found the warm climate over the continents, which they required (p. 567). Now, the modern species correspond to a climate like the present, which is a colder one. The Glutton, of Lapland, the Reindeer, and the Polar Bear were among the earliest of these modern species, showing that when they began this cooler climate existed. Since the faunas of the Post-tertiary and age of Man are thus distinct in the climate which they required, they must have belonged essentially to different epochs,—the modern, of course, to the later. The Terrace epoch was the one in which the change to the colder modern climate was in progress, and therefore that which would have favored the appearance of the modern types and brought about the disappearance of the more ancient.

The cooler climate might have been begun over Europe and Asia in the early part of the Terrace epoch, by an increase of Arctic lands, before the terrace elevations of central Europe had made much progress.

The succession of recent formations in Europe and Switzerland, from the early Post-tertiary onward, is thus given by Professor Guyot from his own and other observations:—

1. The northern European and American Glacial drift, the Glacial epoch.

2. The epoch of subsidence, or Champlain epoch, when the large Post-tertiary fauna was fully developed.

3. The "ancient diluvium" of Switzerland. In some places it is hundreds of feet thick, and generally stratified; part of it is pebbly, with the rounded stones sometimes from the size of an egg to that of a man's head, but none of them are scratched or polished. It covers the plains about Lake Geneva and the lowlands of Switzerland, and underlies the moraines of the great Swiss Glacier (p. 545), and contains, though rarely, bones of the *Ursus spelæus*, *Felis spelæa*, *Elephas primigenius*, *Rhinoceros tichorinus*, *Hippopotamus*, etc., without any remains of modern species.

4. The Drift of the great Glacier of Switzerland, together with the Terraces and Lœss or silt of the river-borders. It may belong to the American Terrace epoch. The true Drift is unstratified, and spreads upward over the hills; the stones are scratched and polished, and in part lie in distinct moraines, or are mixed with glacial mud. The alluvium or lœss covers this Drift. It is well seen in the valley of the Rhine north of Basle, where it overlies the continuation of the old diluvium of Switzerland. It is sometimes one hundred feet thick, and extends up several hundred feet above the bottom of the valley. It contains a vast amount of land-shells, of existing species; but they have the small size and aspect that belong to those now found in the Alps 6000 feet above the sea.

Near Geneva, at Matteguin, there is a bone-bed ten to fifteen feet below the

surface, which was first explored in 1845 by Pictet. It occurs in gravel whose stones are scratched as by glacier action, and overlies a clay containing scratched pebbles, whence, according to A. Favre, it belongs to the epoch of the great Swiss glacier, or that immediately succeeding it, and not to the "ancient diluvium" of Switzerland. It contains remains of various Mammals of existing species, as the Shrew, Mole, Fox, Rat, Mouse, Hog, Ox, Chamois, Stag, etc. The lœss also contains abundant remains of existing Mammals, together with, in some cases, the ancient Elephant, and a few other extinct species.

In North America some of the Mammals appear to date from the Terrace epoch. Among these, according to Holmes and Leidy, there are probably the modern Horse, or one similar to the common species, the gray Rabbit, and Tapir; and to these Dr. Holmes adds the Bison, Peccary, Beaver, Musk-Rat, Elk, Deer, Raccoon, Opossum, Hog, Sheep, Dog, and Ox. The species, however, have not in all cases been identified with certainty; and it is not settled that the commingling of bones is not of more modern origin. In western Canada. Chapman has found remains of the modern Beaver, Musk-Rat, Elk (*Elaphus Canadensis*), and Moose, in stratified gravel which contained also bones of the Mammoth and Mastodon.

The caverns of the country have afforded some Mammalian remains, but only of recent species, though otherwise supposed until recently. In one, near Carlisle in Pennsylvania, Baird found bones of all the species of Mammals of the State, besides one or two other species not now Pennsylvanian, but known in regions not far remote. As a general rule, the bones appeared to indicate that the size exceeded that of the species at the present time.

A few species of animals have become extinct in recent times, and partly through the agency of Man. Among these there are the *Moa* (*Dinornis*), and other birds of New Zealand, and the *Dodo* and some of its associates of Mauritius and the adjoining islands in the Indian Ocean. The species are of the half-fledged Ostrich tribe. Fig. 844 (copied from Strickland's "Dodo and its Kindred") is from a painting at Vienna made by Roland Savery in 1628.

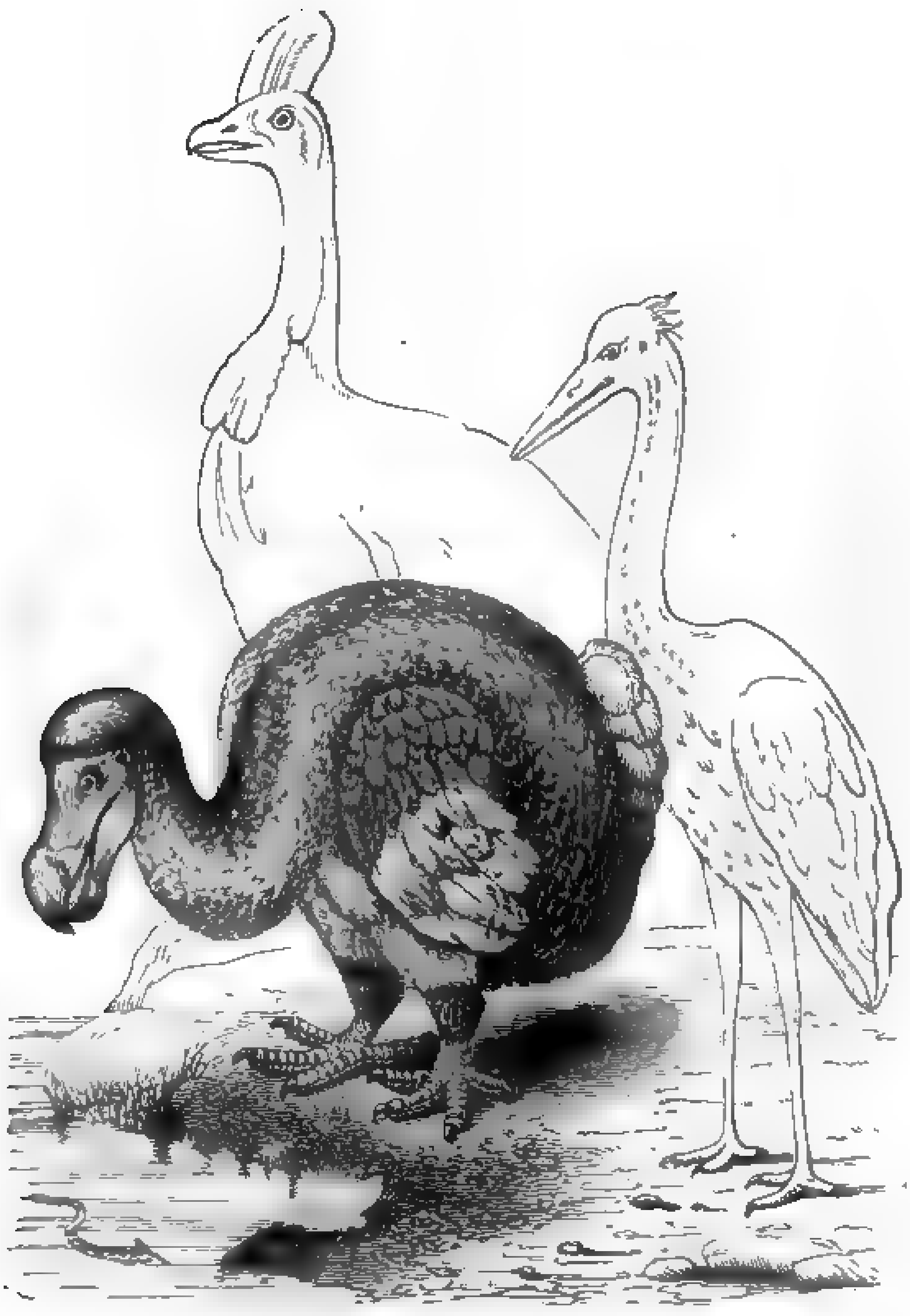
The *Dodo* was a large, clumsy bird, some fifty pounds in weight, with loose, downy plumage, and wings no more perfect than those of a young chicken. The Dutch navigators found it in great numbers in the seventeenth century. But after the possession of the island by the French, in 1712, nothing more is heard of the Dodo; a head, two feet, and a cranium are all that is left, except some pictures in the works of the Dutch voyagers.

The *Solitaire* is another exterminated bird of the same island.

The *Moa* (*Dinornis giganteus*) of New Zealand exceeded the Ostrich in size, being 10 to 12 feet in height. The tibia (drumstick) of the bird was thirty to thirty-two inches in length, and the eggs so large that it is said "a hat would make a good egg-cup for them." The bones were found along with charred wood, showing that they had been killed and eaten by the natives. The name Dinornis is from δεινος, *terrible*, and ορνις, *bird*.

Besides the *Dinornis giganteus*, remains of other extinct species of the genus

Fig. 844.



Dodo, with the Solitaire in the background.

have been found; also extinct species of *Palapteryx* and *Notornis*. *Palapteryx* is related to Apteryx; and both *Apteryx* and *Notornis* have living species.

On *Madagascar* another species of this family of gigantic Ostrich-like birds formerly existed. The species has been called *Æpiornis maximus*. From the bones of the leg it is supposed to have been at least twelve feet in height. The egg was over a foot (thirteen and a half inches) in length.

The great Auk of the North Sea (*Alca impennis*) is reported to be an extinct bird by Prof. Steenstrup. The last known to have been seen were two taken near Iceland in 1844. The bones occur in great numbers on the shores of Iceland, Greenland, and Denmark, showing that it was once a common bird.

A species of Manatee, *Rytina Stelleri* Cuvier, known in the last century on the Arctic shores of Siberia, is now supposed to be extinct.

The Aurochs (*Bos Bison*) of Europe, one of the cotemporaries of the old Elephant (*E. primigenius*), would have long-since been exterminated from Europe but for the protection of Man. Though once abundant, it is now confined on that continent to the imperial forests of Lithuania, belonging to the Russian emperor. It is said to exist also in the Caucasus. The *Bos primigenius* of the Post-tertiary is supposed to be the same with the *Urus* (Ure-Ox or *Bos Urus*) described by Cæsar in his Commentaries, and stated to abound in the Gallic forests, and is a distinct species from the Aurochs, with which it has been confounded. The species is now quite extinct. It is said to have continued in Switzerland into the sixteenth century.

The American Buffalo (*Bos Americanus*) formerly covered the eastern part of the continent to the Atlantic, and extended south into Florida, Texas, and Mexico; but now it is never seen east of the Missouri, excepting its northern portion, and its main range is between the Upper Missouri and the Rocky Mountains, and from northern Texas and New Mexico to Great Martin Lake in latitude 64° N. (Baird.)

The spread of the farms and settlements of civilization is gradually limiting, all over the globe, the range of the wild animals, especially those of large size, and must end in the extermination of many now existing.

Man.—Some of the fossil relics of Man are skeletons or isolated bones,—stone arrow-heads and other implements,—pieces of wood, bone, or stone, hacked or otherwise marked with a tool,—pottery,—bronze implements,—coins,—engraved tablets of stone,—buried cities, such as Nineveh and Pompeii.

One of the most perfect of fossil skeletons found in solid rock is represented in fig. 845. It is from a shell limestone of modern origin, and now in progress, on the island of Guadaloupe. The specimen is in the Museum at Paris. The British Museum contains another from the same region, but wanting the head, which is in the collection of the Medical College at Charleston in South Carolina. They are the remains of Caribs killed in a fight with a neighboring tribe about two centuries since. In the county of Cork, Ireland, a skeleton was formerly obtained beneath a bed of peat eleven feet thick. Fig. 846 represents a ferruginous conglomerate

containing silver coins of the reign of Edward I. and some others, found at Tutbury, England. It was obtained at a depth of ten feet below the bed of the river Dove.

The earliest remains of Man and his art occur with the bones of extinct Post-tertiary animals, in the same conditions as the bones of the modern Mammals above mentioned. They are flint arrow-heads, stone axes, pieces of bone and wood cut or marked, and

Fig. 845.

Human skeleton from Guadaloupe.

Fig. 846.

Conglomerate containing coins.

also some of the bones of skeletons. They have been found in England, France, Switzerland, and some other countries in Europe. The associated extinct animals include the *Elephant* (E. primigenius), *Rhinoceros* (R. tichorinus), *Irish Elk* (Megaceros), and *Cave Hyena*. The localities are bone-caverns and beds of alluvium. The facts appear to place it beyond doubt that Man began to exist before the extinction of the Post-tertiary races, as before stated.

Localities of human relics in stratified deposits.—(1.) Near Abbeville, France, in the valley of the Somme, at Menchecourt and elsewhere, first investigated by B. de Perthes.—The excavations occur in a bed of alluvium (stratified loam, sand, and gravel), situated about ninety feet above the valley; the layers apparently had not been disturbed since their formation under the action of fresh waters. Land-shells (*Helix*, *Pupa*, *Clausilia*) occur in the bed with the arrow-heads; and bones of the old *Elephant* were found in the overlying

sandy layer, and a nearly entire skeleton of a *Rhinoceros* in the inferior bed of gravel.

(2.) Near Amiens, at St. Acheul, and elsewhere in the same valley.—The beds are similar, and are situated eighty-nine feet above the bottom of the valley. Their thickness is twenty to thirty feet. The arrow-heads and hatchets are in gravel resting on chalk; and in the same deposits were found bones of the ancient *Elephant*, *Rhinoceros*, and *Hippopotamus*. Other localities of flint arrow-heads occur in the valley of the Seine near Châtillon-sur-Seine, and in that of the Oise, at Precy.

(3.) At Hoxne, England, five miles east of Diss.—Flint implements occur here in alluvium with land and fresh-water shells and some Mammalian bones,—part of them of extinct species; and it is probable that the deposits date back to the age of the Post-tertiary Mammals. The beds, according to Prestwich, are more recent than the "boulder-clay" of the Glacial period. The period, he observes, "was amongst the latest in geological time,—one apparently immediately anterior to the surface assuming its present form so far as it regards some of the minor features."

Prestwich also remarks that "the evidence" from the occurrence of human relics with the bones of extinct animals, "as it at present stands, does not seem to me to necessitate the carrying of Man back in past time, so much as the bringing forward of the extinct animals towards our own time; my own previous opinion, founded on an independent study of the superficial drift or Pleistocene (Post-tertiary) deposits, having likewise been certainly in favor of this view."

(4.) About several of the Swiss lakes there are the remains of "Lake-habitations," in the shape of piles and platforms for their support, which are in view at occasional low stages of the water. In connection with the structures numerous human relics have been found, such as stone arrow-heads, lance-heads, axes, hammers, bone harpoons, bone arrow-heads, pieces of pottery, but nothing made of metal. According to Keller, 24 of these lake-habitations have been found on Lake Geneva, 26 on Lake Neufchatel, 16 on Lake Constance, 11 on Lake Bienne, besides many on the other lakes. Part, however, belong to the later or "Bronze age."

Rutimeyer states that 66 species of vertebrate animals have been identified in connection with the earliest ruins,—10 of Fishes, 3 of Reptiles, 17 of Birds, and the rest (36) Mammals. Eight of the latter were probably domesticated,—the *Dog*, *Pig*, *Horse*, *Ass*, *Goat*, *Sheep*, and two species of *Oxen*; and among the rest occur bones of the *Aurochs* and *Bison*. As these two species were cotemporaries of the ancient Elephant, it is possible, as Rutimeyer observes, that the structures date back to the earliest tribes of Men in Europe. Yet the absence of the remains of the Elephant and Mastodon seems to show that they belong to a later date than the deposits of Amiens.

Caverns.—Near Aray, in the Department of Aube, according to De Vibraye, a human jaw was found in the same bed which contained remains of *Rhinoceros* and the *Cave Bear* and *Hyena*. In Kent's Cavern near Torquay, England, there are flint arrow-heads; at Brixham, Devonshire, in the superficial stalagmite; and in one near Liege, explored by Schmerling. Other human relics, as fragments of rude pottery and bones, have been found with bones of the ancient Mammals; and they occur in each case in such connections as appear to show

that Man existed before the extermination of the Post-tertiary species. Lartet has described a cave near Auvignac in the vicinity of the Pyrenees (Department of Haute-Garonne), which contains human skeletons, and flint and bone or horn implements, along with fragments of bones or teeth of the *Cave Hyena, Cave Bear, Cave Felis, Fox, Wild Boar, Bison, Stag, Reindeer, Irish Elk,* and others. The bones are supposed to have been carried in by the human inhabitants, and the most of them were from their food. Many show that they had been split open to get out the marrow. Lartet remarks that the people must have been cotemporaries of the Rhinoceros, Hyena, and Gigantic Elk; and even of the Cave Bear, the species among the great Mammals of the Post-tertiary which was probably the earliest to disappear.

Near Palermo, Sicily, there is a cavern containing human relics, along with some remains of extinct animals.

In North America there are no known facts sufficiently well authenticated to be here repeated.

In some of the South American caverns Dr. Lund found human bones along with those of extinct species, and has published as his conclusion that the bones belonged to an ancient tribe which was coeval with some of the extinct Mammals.

As the implements among these early relics are all made of stone, the age in which they occur has been called the *Stone period* (or Stone age), in distinction from the later Bronze or Archaic period, and still later Iron or Teutonic period. But until Asia has been fully explored, and found to afford corresponding facts, the term should be regarded as belonging to European history rather than to that of the human race; and so also with all conclusions with regard to the characteristics of the earliest of mankind derived from the forms of bones or skulls. Geology here passes over the continuation of the history of Man to Archæology.

The observations thus far made appear to accord with the view, already expressed, that in the Terrace epoch there occurred both the decline of the Post-tertiary races and the introduction of the modern tribes of Mammals, together with the creation of Man. Other animal tribes must have been at the same time replenished, especially those of Birds and Insects, which are terrestrial. Among fruits and flowers it is not improbable that many kinds were introduced that added both to the beauty and wealth of the finished world.

As Man was in the prospect through all the progressing changes of earlier time, it is not too much to say that in the final fitting up of the earth with life there was still a reference to him. If creation was the plan of a being of omniscience and wisdom, the end was in the beginning, and in each succeeding step.

In order to appreciate the distinctive features of the age of Man,

or of an age in any history, it is not right to look to its beginning, when the past and future are commingled and the progressing stages are obscured, but onward to a time when the past has faded and the age stands forth in its own true characters. Thus viewed, the Cenozoic and present eras stand widely apart. Both are, approximately, on the same broad foundation of the lower orders of life. But, while the former rises to an eminence in the size and ferocity of its higher brute races, the latter —with more adornment in its tribes, as we may believe, and less bulk by three-fourths in its largest animals, as we know,—with an assemblage of life stripped largely of the animal,—noted neither for Leviathan reptiles, like the meridian of the Mesozoic era, nor for great beasts of prey, like the Cenozoic —culminates in Man, with whom all is in harmony. It has its true affiliation not so much with the past as with the unending future.

Man of one species.—This oneness of species is sustained by the following considerations:—

(1.) The fact of an essential identity among men of all races in physical and mental characteristics.

(2.) The capability of an intermixture of races with continued fertile progeny. The inferior race in case of mixture with a superior may dwindle, the people becoming from their position discouraged, debased, and, in their poverty and superstition, an easy prey to disease; and it may possibly die out, as the weaker weeds disappear among the strong-growing grass: such decay is hence no evidence that there is a natural limit to the fertility of "mixed breeds," as some have urged.

(3.) Among Mammals, the higher genera have few species, and the highest group next to Man, that of the Ourang-outang, contains only eight; and these eight belong to two genera,—*five* of them to the genus *Pithecus*, of the East Indies, and *three* to the higher genus *Troglodytes*, of Africa. Analogy requires that Man should here have pre-eminence. If more than one species be admitted, there is scarcely a limit to the number that may be made.

The investigations of Darwin on the variations of species, and other facts of like character, set aside objections to an origin from one stock arising from the diversities of the races.

These are some of the reasons for believing that Man stands alone—the one sole species—at the head of the kingdoms of life.

Origin on only one of the two great continents.—Among the higher Mammals no species is known to have existed originally within the tropics or temperate zones on both the oriental and occidental continents (the former including Europe, Asia, and Africa, the latter,

North and South America); and, more than this, species have a limited range on that particular continent to which they are confined.

The same species among the Monkeys—the tribe at the head of brute Mammals—in no instance occurs on both; nor even the same genus; nor even the same family; for the American type is that of the inferior *Platyrrhines*, while the African is that of the *Catarrhines* (p. 422), which most approach Man in their features and structure. This is only the highest of an extensive range of facts in Zoology sustaining the principle in view. If, therefore, Man is of one species, he should be restricted also to one continent in his origin.

Moreover, Man's capability of spreading to all lands, and of adaptation to all climates, renders creation in different localities over the globe eminently unnecessary and directly opposed to his own good. It would be doing for Man what Man could do of himself. It would be contracting the field of conquest before him in nature, thereby lessening his means and opportunities of development.

Origin on some part of the Oriental continent.—The Orient has always been the continent of Progress. From the close of the Palæozoic its species of animal life have been three times as numerous as those of North America, and more varied in genera. In the early Tertiary its flora in the European portion had an Australian type, and there were Marsupials and Edentates there. In the middle and later Tertiary it represented recent North America in its flora. But from this condition it emerged to a higher grade. In the Post-tertiary it became the land of the Carnivores, while North America was the continent as distinctively of Herbivores,—an inferior type,—South America, of Edentates,—still lower,—Australia, of the lowest of quadrupeds,—the Marsupials. In the closing creations Australia remained Marsupial, though with dwindled forms; South America was still the land of Edentates, but of smaller species, and with inferior Carnivores and the inferior type of Monkeys or Quadrumana; North America, of Herbivores, also small compared with the Post-tertiary; while the Orient, besides its new Carnivores, received the highest of the Quadrumana. Thus the Orient had successively passed through the Australian and American stages, and, leaving the other continents behind, it stood in the forefront of progress. It is therefore in accordance with all past analogies that Man should have originated on some part of the great Orient; and no spot would seem to have been better fitted for Man's self-distribution and self-development than southwestern Asia,—the centre from

which the three grand continental divisions of Europe, Asia, and Africa radiate.

No creations since that of Man.—It is not known that any new species of plants or animals have appeared on the Earth since the creation of Man.

III. Changes of level on the Earth's surface.

Although the earth, in this its last age, has reached a state of comparative stability, changes of level in the land still take place. The movements are of two kinds:—

1. Secular, or movements progressing slowly by the century.
2. Paroxysmal,—taking place suddenly, in connection usually with earthquakes.

1. *Secular.*—The secular movements which have been observed are confined to the middle and higher temperate latitudes, and are evidently a continuation of the series which characterized the Post-tertiary period. In this and other dynamical changes the Post-tertiary and the age of Man have intimate relations. The movements of the former were directly anticipatory of the latter.

The coast of Sweden and Finland on the Baltic has been proved, by marks made under the direction of the Swedish government, to be slowly rising. The change is slight at Stockholm, but increases northward, and is felt even at the North Cape,—an extent north and south of one thousand miles. Lyell, in 1834, estimated the rise at Uddevalla at nearly or quite four feet in a century, and he made it still greater to the north. The fact of the slow elevation was first suspected a century and a half since. Here, then, is slow movement by the century, such as characterized the great changes of level in past ages.

Beds of recent shells are found along the coast at many places, at heights from 100 to 700 feet. Part of these may be of Post-tertiary date. Two miles north of Uddevalla, Lyell found barnacles on the rocks over 100 feet above the sea; and there are shell-beds at a height of 400 feet. The former at least belong probably to the present era. Southwest of Stockholm other beds of shells occur, and the same dwarfish species that now live in the partly-freshened waters of the Bothnian Gulf.

There are also near Stockholm proofs of a former subsidence since fishing-huts were built on the coast. A fishing-hut, having a rude fireplace within, was struck, in digging a canal, at a depth of sixty feet. It is a common belief that over southern Sweden a very slow subsidence is now in progress.

In Greenland a slow subsidence is taking place. For 600 miles from Disco Bay, near 69° N., to the Firth of Igaliko, 60° 43′, the coast has been sinking for four centuries past. Old buildings and islands have been submerged, and the Moravian settlers have had to put down new poles for their boats, and the old ones stand, Lyell observes, "as silent witnesses of the change."

On the North American coast south of Greenland, along the coasts from Labrador to New Jersey, it is supposed that similar changes are going on; though more investigation is required to establish fully the fact. G. H. Cook concludes from his observations that a slow elevation is in progress along the coast of New Jersey, Long Island, and Martha's Vineyard (Am. Jour. Sci. [2] xxiv. 341); and, according to A. Gesner, the land is rising at St. John's in New Brunswick; sinking at the island of Grand Manan; rising on the coast opposite, at Bathurst; sinking near the Bay of Fundy and Basin of Mines in Nova Scotia, except, perhaps, on the south side, and rising at Prince Edward's Island.

The Coral Islands of the Pacific are proofs of a great secular subsidence in that ocean. The line C C C (Physiographic Chart) between Pitcairn's Island and the Pelews divides coral islands from those not coral; over the area north of it to the Hawaian Islands all the islands are atolls, excepting the Marquesas and three or four of the Carolines. If then the atolls, as will be shown on a future page, are registers of subsidence, a vast area has partaken in it,—measuring 6000 miles in length (a fourth of the earth's circumference) and 1000 to 2000 in breadth. Just south of the line there are extensive coral reefs; north of it the atolls are large, but they diminish towards the equator and disappear mostly north of it; and as the smaller atolls indicate the greater amount of subsidence, and the absence of islands still more, the line A A may be regarded as the axial line of this great Pacific subsidence. The amount of this subsidence may be inferred, from the soundings near some of the islands, to be at least 3000 feet. But as two hundred islands have disappeared, and it is probable that some among them were at least as high as the average of existing high islands, the whole subsidence cannot be less than 6000 feet. It is probable that this sinking began in the Post-tertiary period.

Since this subsidence ceased—for the wooded condition of the islands is proof of its having ceased—there have been several cases of isolated elevations. The following are some of the islands that have been elevated:—Oahu (Hawaian Islands), 25 feet; Elizabeth Island, Paumotu Archipelago, 80 feet; Metia or Aurora, 250 feet; Atiu, Hervey Group, 12 feet; Mangaia, 300 feet; Rurutu, 150 feet;

Eua, Tonga Group, nearly 300; Vavau, 100; Savage Island, 100. Many others have been raised to a less amount.

2. *Paroxysmal.*—The changes of level about Pozzuoli near Naples, at Cutch in the Delta of the Indus, and on the Chilian coast, South America, are noted examples of modern change of level. The first appears to have been gradual in its progress; but, if so, it is not properly secular in the sense in which that term is used. The cases at Cutch and in Chili were connected with earthquakes; the other is in the volcanic region of southern Italy.

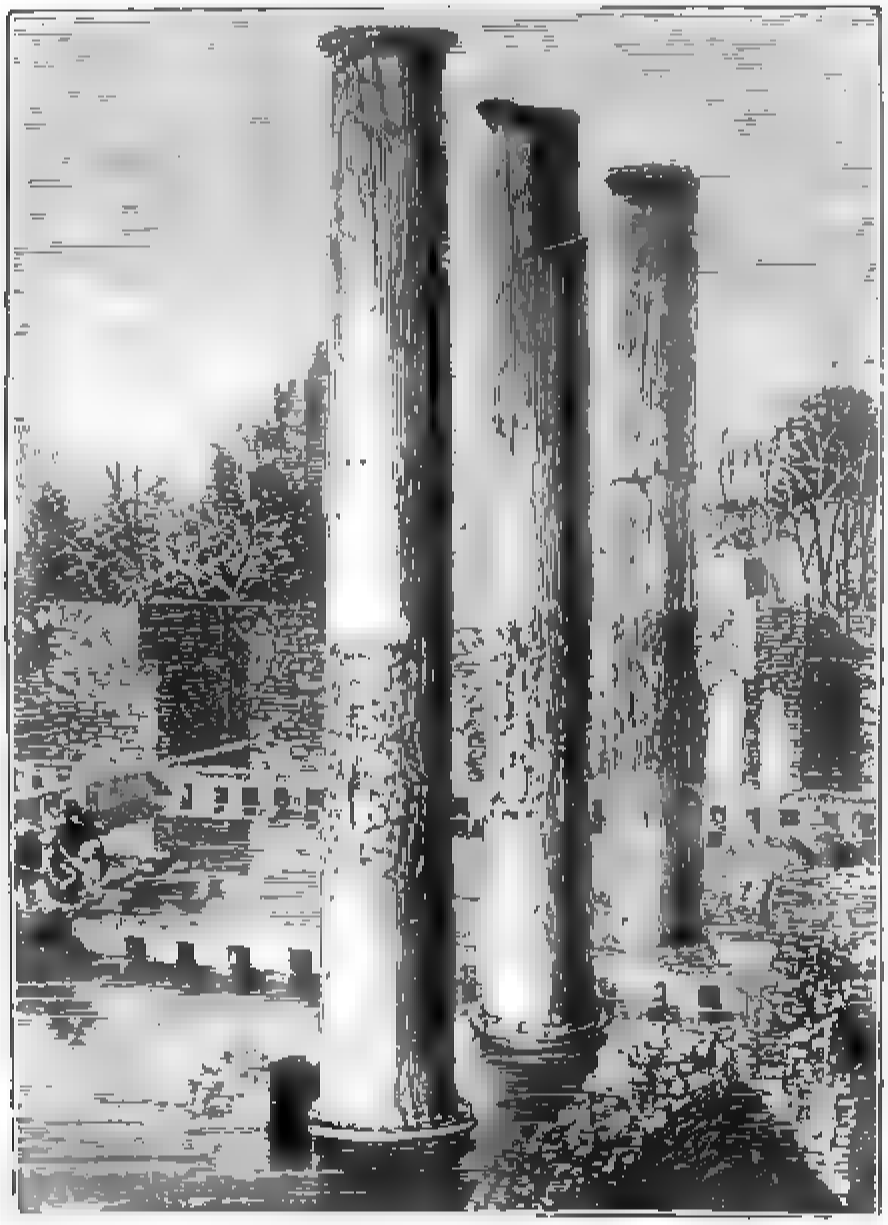
The temple of Jupiter Serapis at Pozzuoli was originally 134 feet long by 115 wide, and the roof was supported by forty-six columns each forty-two feet high and five in diameter. Three of the columns are now standing: they bear evidence, however, that they were once for a considerable time submerged to half their height. The lower twelve feet is smooth; for nine feet above this they are penetrated by lithodomous or boring shells, and remains of the shells (a species now living in the Mediterranean) were found in the holes. The columns when submerged were consequently buried in the mud of the bottom for twelve feet, and were then in water nine feet deep. The pavement of the temple is now submerged. Five feet below it there is a second pavement, proving that these oscillations had gone on before the temple was deserted by the Romans. It has been recently stated that for some time previous to 1845 a slow sinking had been going on, and since then there has been as gradual a rising.

At the earthquake in 1819 about the Delta of the Indus, an area of 2000 square miles became an inland sea, and the fort and village of Sindree sunk till the tops of the houses were just above the water. Five and a half miles from Sindree, parallel with this sunken area, a region was elevated ten feet above the delta, fifty miles long and in some parts ten broad. The natives, with reference to its origin, call it Ullah Bund, or Mound of God. In 1838 the fort of Sindree was still half buried in the sea: and during an earthquake in 1845 the Sindree Lake was turned into a salt marsh.

In 1822 the coast along by Concepcion and Valparaiso, for 1200 miles, was shaken by an earthquake; and it has been estimated that the coast at Valparaiso was raised three or four feet. In February, 1835, another earthquake was felt from Copiapo to Chili, and east beyond the Andes to Mendoza. Captain Fitzroy states that there was an elevation of four or five feet at Talcahuano, which was reduced by April to two or three feet. The south side of the island of Santa Maria, near by, was raised eight feet, and the north ten.

and beds of dead mussels were found on the rocks ten feet above high-water mark.

Fig. 847.



Temple of Jupiter Serapis.

Thus the earth, although in an important sense finished, is undergoing changes from paroxysmal movements and prolonged oscillations. The changes, while more restricted than in the ages of progress, are yet the same in kind.

GENERAL OBSERVATIONS ON GEOLOGICAL HISTORY.

1. LENGTH OF GEOLOGICAL TIME.

On former pages (pp. 386, 493, 568) estimates have been given of the relative lengths of the ages and periods, or their time-ratios. Future discovery will probably enable the geologist to determine these ratios with far greater certainty and precision.

Although Geology has no means of substituting positive lengths of time in place of such ratios, it affords facts sufficient to prove the general proposition that Time is long; and a few examples are here given.

Niagara has made its gorge by a slow process of excavation, and is still prolonging it towards Lake Erie. Near the fall it is 200 to 250 feet deep, and at the fall itself 160 feet,—the lower 80 feet shale, the upper 80 limestone. The rocks dip 15 feet in a mile up stream, so that the limestone becomes thicker as it recedes on its course. The waters wear out the shale, and thus undermine the limestone. The distance from Niagara to the Queenstown heights which face the plain bordering Lake Ontario is seven miles.

On both sides of the gorge near the whirlpool (three miles below the fall), and also at Goat Island, there are beds of recent lake-shells, Unios, Melanias, and Paludinas, the same kinds that live in still water near the entrance to the lake, and which are not found in the rapids. The lake, therefore, spread its still waters, when these beds were formed, over the gorge above the whirlpool. A tooth of a Mastodon has been found in the same beds. This locates the time in the Champlain epoch. Moreover, the waters would not have been set back to the height of these beds unless they extended on below for at least six miles from the falls. Six miles of the gorge have, then, been excavated since that Mastodon was alive. There are terraces in the shell deposits showing changes of level in the lakes.

There is a lateral valley leading from the whirlpool through the Queenstown precipice at a point a few miles west of Lewiston. This valley is filled with drift of the Glacial epoch, as stated on p. 536; and this blocking up of the channel may have compelled it to open a new passage.

If, then, the falls have been receding six miles, and we can ascer-

tain the probable rate of progress, we may approximate to the length of time it required. Hall and Lyell estimated the average rate at one foot a year,—which is certainly large. Mr. Desor concluded, after his study of the falls, that it was "more nearly three feet a century than three feet a year." Taking the rate at one foot a year, the six miles will have required over 31,000 years; if at one inch a year,—which is 8⅓ feet a century,—380,000 years. These calculations may be taken as data for estimating the length of time required for excavating the great gorge of the Colorado mentioned on p. 569,—300 miles long and 3000 to 6000 feet deep, some hundreds of feet of the depth being for much of the distance through granite. The whole was probably accomplished after the close of the Mesozoic.

The rate at which coral reefs increase in height affords another mode of measuring the past. The rate of growth of the common branching Madrepore is not over one and a half inches a year. As the branches are open, this would not be equivalent to more than half an inch in height of solid coral for the whole surface covered by the Madrepore, and, as they are also porous, to not over three-eighths of an inch of solid limestone. But a coral plantation has large bare patches without corals; and the coral sands are widely distributed by currents, part of them to depths over one hundred feet, where there are no living corals; not more than one-sixth of the surface of a reef-region is in fact covered with growing species: this reduces the three-eighths to *one-sixteenth*. Shells and other organic relics may contribute one-fourth as much as corals. At the outside, the average upward increase of the whole reef-ground per year would not exceed *one-eighth* of an inch.

Now, some reefs are at least 2000 feet thick, which, at one-eighth of an inch a year, corresponds to 192,000 years. If the progressing subsidence essential to the increasing thickness were slower than the most rapid rate at which the upward progress might take place, the time would be proportionally longer.

The use of these numbers is simply to prove the proposition that Time is long,—very long,—even when the earth was hastening on towards its last age. And what, then, of the series of ages that lie back of this in time?

In calculations of elapsed time from the thickness of formations, there is always great uncertainty arising from the dependence of this thickness on a progressing subsidence. In the case of coral limestone the data employed give the *least* possible time, as is obvious from the above. In estimates made from alluvial deposits, when the data are based on the thickness of the accumulations in a given number of years,—say the last 2000 years,—this source of doubt affects

the whole calculation from its foundation, and renders it almost, if not quite, worthless. An estimate of the length of the Miocene epoch made from data derived from observations on the deposits then forming in England would have given no idea of the length of time required for the Miocene molasse of Switzerland; and, in the same manner, any such data from observations at the present day must be equally fallacious. When the estimate, as from delta deposits, is based on the amount of detritus discharged by a stream, it is of more value. But even here there is a source of great doubt, in our ignorance of the oscillations the continent may have undergone in past time, which, especially if an upward movement, would have affected the amount of discharge. This source of doubt affects also the calculations from the excavation of valleys.

2. GEOGRAPHICAL PROGRESS IN NORTH AMERICA.

The system of oscillations and progress during the ages to the close of the Tertiary period, and the new system which succeeded and characterized subsequent time, have been discussed in the course of the General Observations on the Azoic, Palæozoic, Mesozoic, and Cenozoic eras; and the reader is here referred to pp. 144, 388, 502, and 568, a recapitulation in this place being unnecessary.

3. PROGRESS OF LIFE.

Several general principles connected with the progress of life have been illustrated in the course of the preceding history. They are here brought together and presented briefly and more systematically. The subject may be considered under two heads:—*first*, the system in the progress of life; *second*, the relations of the progress of life to the physical progress of the globe.

1. System in the Progress of Life.*

1. *Reality of the progress.*—(1.) In geological history, Mollusks, Corals, and Crinoids are at one end of the series of animal life, Man

* The following are some of the *Criteria of rank* among Animals:—

(1.) Under any type, *water-species are inferior to land-species*: as the Seals to the terrestrial Carnivores; the water-articulates or Worms and Crustaceans to land-articulates or Spiders and Insects.

(2.) *Species of a tribe bearing some of the characteristics of an inferior tribe or class are inferior species, and conversely.*—Thus, Amphibians show their inferiority to True Reptiles in the young having gills like Fishes; the early Thecodont Reptiles, inferiority to the later in having biconcave vertebræ, like Fishes; the Marsupials and Edentates, inferiority to other Mammals in having the sacrum consisting of only two united vertebræ, as in most Reptiles. On the contrary, the Dinosaurs show their superiority to other Saurians in having the sacrum made of five (or six) vertebræ, as in the higher Mammals.

at the other; and if Protophytes or any Algæ, and Protozoans, commenced in the later part of the Azoic (which is shown to be pro-

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(3.) *As a species in development passes through successive stages of progress, relative grade in inferior species may often be determined by comparing their structures with these embryonic stages.*—As a many-jointed larve without any distinction of thorax and abdomen is the young state of an Insect, therefore Myriapods or Centipedes, which have the same general form, are inferior to Insects. As a young living Gar has a vertebrated caudal lobe (making an accessory upper lobe to the tail), which it loses on becoming adult, therefore the older Ganoids with vertebrated tails (or heterocercal) are inferior to the later in which the tails are not vertebrated (or are homocercal). As the young of a Frog (a tadpole) has the tail and form of a Salamandrian, therefore the Salamandrians are inferior to Frogs. As the number of segments in the young of Insects often exceeds much that of the adult, therefore species of adult animals in which there is an excessive number of segments (beyond the typical number) have in this a mark of inferiority; and thus the Phyllopods and Trilobites among Crustaceans bear marks of inferiority, the typical number of segments in the abdomen of a Crustacean being but seven, and in the whole body twenty-one,—each pair of members corresponding to *one*, commencing with the eyes as the anterior.

Professor Agassiz has brought out and illustrated in his writings each of the above Criteria.

(4.) *Species having the largest number of distinct segments in the posterior part of the body, or having the body posteriorly prolonged, are the inferior among those under any type.*—Shrimps and Lobsters are thus inferior to Crabs; Centipedes, to Insects; Salamandrians, or tailed Batrachians, to the Frogs or tailless Batrachians; Snakes, to Lizards; the Ganoids with vertebrated tails, to those with non-vertebrated. It does not follow on this principle that Frogs, although tailless, are superior to Lizards; for they are of different types of structure.

(5.) *Species having the anterior part of the body most compacted or condensed in arrangement, or having the largest part of the body contributing to the functions of the head-extremity, are the superior, other things being equal.*—Thus, Man stands at the head of all Vertebrates in having only the posterior limbs required for locomotion, the *anterior having higher uses;* and also in having the head most compacted in structure and brought into the least compass consistent with the amount of brain. In the same manner, the Carnivores among the large Mammals (Megasthenes) are superior to the Herbivores, the anterior limbs not having locomotion as their sole use, and the head being more compacted and condensed for the size of brain. The highest Crabs, the Triangular or Maioids, are superior in the same manner to the lower, and far more to the Lobster tribe and other Macrourans; descending in grade from the higher Crabs, the outer mouth-organs become more and more separated from the mouth, and finally, in many Macrourans, they have the form of feet, thus passing from the head-series to the foot-series. Insects are on this principle superior as a class to Crustaceans, although of so much less size.

Condensation anteriorly and abbreviation posteriorly is the law of all progress in embryonic development, and also of relative rank among species of related groups.

bable on p. 147), the beginning of the series is even below the types of Mollusks and Trilobites. (2.) Fishes preceded Reptiles; Reptiles, Mammals; brute Mammals, Man. (3.) Articulates commence with the inferior marine species, Worms and Crustaceans; they rise in the Carboniferous age to Insects, the superior class; and later to the highest Insects, the Hymenopters (the tribe containing the Bee). (4.) Crustaceans are first represented by Entomostracans, as Trilobites; then by the Shrimp and Lobster tribes, in the Carboniferous and Reptilian ages; then true Crabs, in the later Reptilian and Mammalian ages; and finally the highest division of Crabs (the Maioid, or Triangular), in the age of Man.

2. *A type not instituted usually by the introduction of its lowest species, or developed by the appearance of species in the order of grade.*—(1.) Snakes, while inferior to Turtles, Saurians, and Lacertians, are not known as fossils until the Tertiary. (2.) Edentates are not known until after the Pachyderms and Carnivores of the early Tertiary. (3.) Mosses and Lichens appear long after the great Acrogens of the Carboniferous Age. (4.) Ganoids and Selachians are not the lowest of fishes in rank. (5.) Trilobites of the oldest Silurian are not the lowest of Crustaceans. Barnacles rank much below them, and yet are not known until the middle of the Reptilian age.

The grand series taken as a whole was an ascending one, but not by lineal ascent from the lowest to the highest.

3. *The culmination of the various groups of species, or their time of greatest expansion, not confined to any one period in geological history; but each group having its own special time, some passing it in the Palæozoic, others in the Mesozoic or Cenozoic, and others not having reached it before the age of Man.*—Numerous examples of this general truth are presented in the tables on pp. 400 and 572, and special examples are also mentioned on pp. 399 and 496.

The culmination of a type is marked in the culmination or greatest expansion of the highest group under the type, and not by that of all the groups which constitute it. See p. 496 for examples.

The Vegetable and Animal kingdoms have now their periods of culmination. But, excluding Man, the Animal kingdom passed its climax in the Post-tertiary, when the Carnivores and Herbivores were largest and most numerous.

Under the Animal kingdom, the sub-kingdom of Mollusks culminated in the later Mesozoic, when Cephalopods, the highest group, passed their climax; that of Articulates, in the present era, when Insects are most diversified and most abundantly represented in the higher groups; that of Vertebrates, exclusive of Man, in the Post-tertiary, the period being the same as for the Animal kingdom as a whole, since it is the highest of the subdivisions.

Under Articulates, Insects, Spiders, and also Crustaceans, have their culmination in the present era.

Under Vertebrates, Fishes appear to have culminated in the Tertiary period, when the highest Sharks existed and were in great numbers; Amphibians, in the Triassic period; True Reptiles, at the close of the Jurassic or commencement of the Cretaceous; Birds, in the present era; Mammals, Man excluded, in the Post-tertiary.

4. *The earliest types representing a group often comprehensive types.*—Comprehensive types have been explained to be those which embrace, along with the characteristics of the group to which they belong, others of another group; and usually at their first appearance this other group is not yet in existence. Examples are mentioned on pp. 395, 500.

They are in part *intermediate types* between two groups, although never occupying the middle point, as they always belong fundamentally to one of the two. They are often more normal or regular in structure than later species of the class or group, so far as this is consistent with the above law,—the more abnormal or less typical forms being of later origin. The earliest Mammals included Marsupials, in accordance with the first law,—species which have, along with the Mammalian structure, some of the characteristics of Birds and Reptiles, and which were therefore fit inhabitants of the Reptilian age. With them there appear to have been species of Insectivores, one of the more typical groups among the Microsthenes (p. 423), and none of the inferior abnormal Edentates. In the Mammalian age the earliest species were certain peculiarly typical Pachyderms and Carnivores (p. 527). The low Edentates, or Sloth tribe, appeared at a still later epoch. Two grand facts connected with comprehensive types are, hence, their partly *intermediate* position, and their comparatively *normal* or regular structure.

The idea of *comprehensive* types was first recognized by Agassiz in the Ganoid fishes. It was afterwards brought out by Owen in an article on the Labyrinthodont Reptiles; and also by Bronn. Agassiz, as stated on p. 203, has called them *synthetic* types. Bronn named them *complex* types (Complications-Typen), an objectionable name, as they are not complex, but, on the contrary, often in their very nature simpler than the later groups which were foreshadowed.

5. *The earliest types, as shown by Agassiz, sometimes having certain characteristics which may be styled embryonic*, being such as are presented by embryos or young individuals of the tribe at the present time. This principle flows out of the general truth that there is a degree of parallelism between the grades of species in a group and the successive stages in the embryonic development of an individual animal in that group. Thus, the early Ganoids had a cartilaginous vertebral column like the *young* of modern Gars, and the

central part of the spinal cord (notochord) remains persistent; they have also a vertebrated tail, like young Gars, as observed by Agassiz.

6. *The species under the early comprehensive types not the lowest species of the group represented.*—This follows from the proposition on p. 583.

7. *In the first appearance of a group (as that of Vertebrates, or that of Reptiles,) the species are often from near the junction of its inferior and superior subdivisions,—species from the middle or upper portion of the inferior either occurring alone, or else associated with others from the middle or lower portion of the superior. The former frequently pertain to a comprehensive type, which is intermediate between the two subdivisions, though belonging usually to the inferior: sometimes there is more than one comprehensive type, as in the case of land-plants.*—This principle is announced and briefly illustrated on page 396.

A more systematic exhibition of the principle is here given.

The following are the two grand subdivisions in some of the higher groups in Nature,—the first mentioned being the *inferior*, the other the *superior*. The latter is also the more typical group, or that in which the idea of the type is more fully represented:—

a. Life in general.—(1.) Vegetable kingdom; (2.) Animal kingdom.

b. Vegetable kingdom.—(1.) Cryptogams, or flowerless plants; (2.) Phænogams, or flowering plants.

c. Animal kingdom.—(1.) The flower-like type, including Radiates; (2.) the true Animal type, or cephalized species, that is, those having a head (or anterior and posterior polarity with bilateral symmetry), including Mollusks, Articulates, and Vertebrates.

d. Sub-kingdom of Mollusks.—(1.) The flower-like type, including the Bryozoans, closely like flowers, the Brachiopods, which also in general were attached below by stems or pedicels, and Ascidians, also, often attached and many radiated exteriorly; (2.) the true Molluscan type, including Acephals, Cephalates, and Cephalopods.

e. Sub-kingdom of Vertebrates.—(1.) Water-vertebrates, including Fishes; (2.) Land-vertebrates, including Reptiles, Birds, and Mammals.

f. Class of Crustaceans.—(1.) Entomostracans; (2.) Malacostracans.

g. Class of Reptiles.—(1.) Amphibians; (2.) True Reptiles (p. 344).

h. Class of Mammals.—(1.) Marsupials, or Semi-oviparans; (2.) Non-marsupials, or typical Mammals (p. 423).

1. Life in general.—In the *inferior* subdivision the earliest species of life were probably the *Protophytes*,—these and other Algæ commencing in the later Azoic. They have the locomotive powers of animals, and may therefore be regarded as an example of one of the comprehensive types, and the *first*. The Protozoans (Rhizopods, etc.) may have been the *associated* species of the *superior* group, as remarked on page 147. The two are alike in extreme simplicity of organization. In Algæ the Radiate type of structure, characteristic of the typical plant, is not brought out; and in Protozoans neither of the four great Animal types appears,—the Radiate, Molluscan, Articulate, or Vertebrate.

If, therefore, these simple species existed in the Azoic era, they were systemless life, and only foreshadowed the great systems of life which were afterwards displayed according to their respective types in the true *Zoic* ages.

2. KINGDOMS.—(*a.*) *Vegetable.*—The earliest Land-plants included Acrogens or the superior Cryptogams, and Conifers or the inferior Phænogams; and among them there were the intermediate comprehensive types of Lepidodendrids, Calamites, and Sigillarids. See p. 283.

(*b.*) *Animal.*—Among the earliest of Animals in the Primordial there were the Cystids (Crinoids). These belong to the Echinoderms, which make the upper portion of the *inferior* subdivision of animals; and they are a comprehensive type between Radiates and Mollusks (the lower portion of the *superior* subdivision). Some early kinds have almost the same absence of symmetry in the body that belongs to Mollusks, and are furnished with only two arms. The *associated superior* species were Mollusks and Articulates; and the earliest Mollusks, the Lingulæ, and others among Brachiopods, stood on a stem like the Cystids, and had also two arms.

3. SUB-KINGDOMS.—(*a.*) *Mollusks.*—The Mollusks of the earliest or Primordial period were from the higher group of the *inferior* division, that is, the Brachiopods. The *associated superior* species comprised Cephalates before Acephals,—that is, the middle before the *inferior* group.

(*b.*) *Vertebrates.*—The earliest Vertebrates were of the *inferior* subdivision, or that of Fishes, and from its upper portion,—that is, the orders of Ganoids and Selachians. The Ganoids were a comprehensive type foreshadowing the lower group of the *superior* division of Vertebrates,—that is, Reptiles (p. 302), which group did not make its appearance until the close of another age.

4. CLASSES.—(*a.*) *Gymnosperms in the Vegetable kingdom.*—The group of Cycads is one of the most marked of comprehensive types, as explained on page 418.

(*b.*) *Crustaceans.*—The earliest Crustaceans, commencing even in the lowest Primordial, were Trilobites, ranking with the highest of Entomostracans, or the *inferior* subdivision, or even above their true level. They constitute a comprehensive type, foreshadowing the Tetradecapods, which are not known to have appeared before the Carboniferous age (p. 375). There was also another comprehensive type in the same early strata,—the Phyllopods, foreshadowing the still higher division of Decapods, which appeared under the form of Macrourans at the same time.

(*c.*) *Reptiles.*—Among the earliest Reptiles in the Carboniferous age there were the Labyrinthodonts,—the highest of the *inferior* division, a comprehensive type having many characteristics of true Reptiles (p. 345). The *associated* species were other Amphibians; also species of the lower groups of the *superior* division,—that is, the lower Lacertians and Swimming Saurians (p. 351).

(*d.*) *Mammals.*—The earliest Mammals were Marsupials of the *inferior* subdivision, and Insectivores of the *superior;* and the order of Insectivores is a typical one among the lower *superior.* See, further, Appendix F.

8. *Comprehensive types generally becoming nearly or quite extinct in the course of future progress.*—See page 397 for illustrations.

9. *Unity in the successive Floras and Faunas of the ages.*—The unity or harmonious character of the Flora of the Carboniferous age, and the dependence of this unity on the principle just explained, is the subject of remark on page 396. It is a marked feature of each of the ages.

If the view of the Azoic age given on page 596 is right, this unity was strikingly brought out in the first expression of life. In the Primordial life this unity is equally marked. There were Brachiopods on stems, associated with the unsymmetrical Cystids, also on stems, and more flower-like;—and, with these sedentary species, the Trilobite, nearly as sedentary in habit,—for it seems to have clung to any supporting surface, like a limpet, though capable of swimming off or crawling over the sea-bottom. The Gasteropods, Pteropods, and Phyllopods were the more active species. A little later, before the close of the Primordial period, there were bivalve Crustaceans in harmony with the bivalve Brachiopods. There was also a new type, indicating progress, in the large and active Cephalopods, the Orthocerata, etc.

The same general features continued to characterize the Lower and Upper Silurian, only with additions to the flower-like animals in Corals, Crinoids, and Bryozoans, and an increase in the diversity of Brachiopods and Trilobites. The unity also appears in the simplicity of structure of the several types.

In the Mesozoic Fauna there was also a wonderful harmony, as explained on page 501. In the Mesozoic Flora there was a unity as striking as in the Carboniferous. Conifers, Tree-ferns, and Cycads made up the bulk of the trees, and the last type, while fundamentally related to the Conifers, partook somewhat of the character of the Tree-fern in its mode of growth. At the same time, this comprehensive type had some characteristics of the palm,—the type it foreshadowed, and which, before the close of the Mesozoic, was already in the forests along with the highest type of plants, the Angiosperms.

10. *Progress always an unfolding of a type or an exhibition of it in its possible diversities, and involving the introduction of inferior as well as superior species.*—It has been already shown that the progress was not a lineal upward progress. The facts with regard to comprehensive types and the associated species throw this principle into a strong light; for these species occupy nodal points, as they may be called, or points of divarication, far remote in most cases from the lowest species of a group.

The progress was not necessarily attended with much rise in grade. The earliest fishes are of the highest orders in that class. These orders undergo some little elevation in after-time; but in the introduction of the Teliosts, or common fishes, in which the great expansion ultimately takes place, there is a fall below the level of the early orders.

In all cases, however, there was an unfolding of a type,—an exhibition of it through the successive appearance of new groups, in which groups characteristics before only foreshadowed, or existing only in potentiality, come out into full expression. The early general or comprehensive type thus becomes in a sense specialized, or represented in numbers of special groups. In the case of Fishes, the type, when the Teliosts appeared, came forth in its purity, deprived of the Reptilian features of the Ganoids (marked in their vertebræ, teeth, air-bladder, and other parts) and developed in those points which make up the true Fish. Moreover, the Fish-type was at the same time represented under a diversity of tribes, and an extraordinary variety of shapes, normal and abnormal, high and low (some almost of the low grade of a Polyp), which was in great contrast with the uniformity of structure and limited variation of form in the Ganoids. Nature thus revels in exuberance when displaying a type after its true level is attained.

In this kind of progress there is naturally expansion towards inferior as well as superior grades: it is not out of harmony with the system that Echinoderms should have existed before Polyps, Tree-ferns and Lepidodendrids before Mosses, Lacertians and Crocodiles before Snakes, or Herbivores and Carnivores before Sloths.

When a type had passed its culmination, there was sometimes a very marked decline in the character of the species that preceded its final extinction. Examples of this have been referred to in the last of the *Leptænæ* that occurred in the Mesozoic (p. 450), and the multiplication of uncoiled forms of the Ammonite family which took place in the Cretaceous (p. 472).

This law of specialization—the general before the special—is the law of all development. The egg is at first a simple unit; and, gradually, part after part of the new structure is evolved, that which is most fundamental appearing earliest, until the being is complete in all its outer and minor details. The principle is exhibited in the physical history of the globe,—which was first a featureless globe of fire, then had its oceans and dry land, in course of time received mountains and rivers, and finally all those diversities of surface which now characterize it. Again, the climates began with universal tropics; gradually, zones were apparent; and at last the diversity of the present day.

But there is a wide distinction in the kind of specialization which starts from a simple unit like an egg, and that proceeding from comprehensive types among plants and animals. The one is diversity out of memberless simplicity; the other, diversity from a unit of

complex structure. The latter is simply an exhibition of the general law of succession in the creations by which the system of life reached its completion.

2. Relation of the History of Life to the Physical History of the Globe.

1. *The plan of progress was determined with reference to the last age, with all its diversities of climate, continental surfaces and oceans, as its era of fullest exhibition.*

2. *The progress in climate and other conditions involved a concurrent progress from the inferior living species to the superior.*—The existence of a long marine era, through the Silurian and part of the Devonian ages, admitted only of the existence of marine life. Hence the dominant type of the Silurian was the Molluscan, which, with the Radiate, is eminently marine. In addition, there were marine Articulates and marine plants: and when the Vertebrates began it was with marine species, the Fishes. Thus the prevalence of waters involved inferiority of species. The increase of land, gradual purification of the atmosphere, and cooling of the globe, prepared the way for the higher species.

It is probable that the oceanic waters were also in an impure state compared with the present, from containing an excess of salts of lime; and this also involved the existing of inferior species,—such as Crinoids, Corals, and Mollusks, a very large proportion of whose weight is in calcareous material. The removal of this excess of lime from the waters produced limestone strata, purified the waters, and fitted the oceans for other species.

The great prevalence, in the Primordial, of Lingulæ (whose shells contain a large amount of phosphate of lime) is further evidence of the greater density of the waters, and seems to indicate the presence of an excess of phosphates.

3. *The progress in climate and in the condition of the atmosphere and waters involved a localization of tribes in time, or chronographically, just as they are now localized by climate over the earth's surface, or geographically.*—Tribes were made for a special climate or condition of the globe; and when this climate or condition had been passed in the earth's progress, the tribes no longer existed. The culmination of the Reptilian and Molluscan types in the Reptilian age, or of Trilobites and Brachiopods in Palæozoic time, are examples. The former when instituted had those special relations to climate that made the Reptilian age the era of their culmination; just as now palms and bananas reach their perfection only in the equatorial zone; figs in the

tropical; myrtles and laurels, in the sub-tropical; evergreen trees, in the warm-temperate; ordinary deciduous trees, in the cold-temperate; and pines, in the sub-arctic. As there are now these zones on going from the equator to the poles, so there were successive eras passed over from the Silurian—the period of universal warm temperature—to the present age of a frigid arctic, and a mean temperature of 58° to 60° F. Climate may not have been the only cause; but it was one, and of great importance. The Crustacean type is one of those which have culminated in the age of Man; and this accords with the fact that its highest species—the Maioids, or Triangular Crabs—are now most numerous and of the highest rank in the colder temperate zone. It was made to reach its maximum in a cold climate, and therefore in the existing age.

No species survived through all time, and few through two successive periods. The oldest now existing began in the Middle Tertiary, and these were only Invertebrates. The oldest quadruped dates no farther back than the Post-tertiary.

But two genera range through the whole series of ages from the first or Potsdam epoch,—*Lingula* and *Discina*,—enough to manifest the oneness of system from the beginning. There was in general a changing of genera with the successive periods. Even *tribes* wholly disappeared from age to age, as the world outgrew them. Of Trilobites, 500 species once lived, of the Ammonite group, 900 species, all of which are extinct; the Nautilus tribe, 450; three or four species are all that exist. Of Ganoid fishes, 700 species have been discovered; the tribe is now nearly extinct. Thus, the old has passed away as the new has come in. Remains of nearly 40,000 animal species have been gathered from the rocks, all of which are extinct; and, considering how few of the whole number would have become fossilized, this can hardly be one-tenth of the number that have existed and are gone. 2500 extinct species of plants have been found,—which cannot be over a twentieth of all that have covered the earth in its former ages.

4. *The extermination of species was in general due to catastrophes, while the extinction of tribes or higher groups may have been a consequence of secular changes in the condition of the climate, atmosphere, or waters.*—The extermination of species here alluded to, and some of the kinds of catastrophes which caused them, are briefly considered on p. 398.

5. With regard to *the Origination of Species*, Geology suggests no theory of natural forces. It is right for science to search out Nature's methods, and strive to employ her forces—organic or inorganic—in the effort, vain though it prove, to derive thence new living species. The study of fossils has given no aid in this direc-

tion. It has brought to light no facts sustaining a theory that derives species from others, either by a system of evolution, or by a system of variations of living individuals, and bears strongly against both hypotheses. There are no lineal series through creation corresponding to such methods of development. Instead of gradations from Mollusks or Articulates to the lower Fishes, and so on upward, the Fish-type commences near its summit-level, or rather between the level of the typical fish and that of a higher class of Vertebrates. Were either of these plans the system in nature, examples of the blending of species would be common through all the classes, high and low; and North America would afford them as successive stages between the old Elephant or Mastodon and earlier species, and so throughout the various tribes of life, animal and vegetable. But, in fact, appearances suggesting the idea of such shadings among species are exceedingly rare,—wonderfully so, considering that Palæontology has only the imperfect stony secretions of animals to study out, which sometimes afford insufficient distinctions even when perfect and from living species. Under any scheme of development of species from species, the system of life, after ages of progress, would have become a blended mass, —the temple of nature fused over its surface and throughout its structure. The study of the past has opened to view no such result.

Geology appears to bring us directly before the Creator; and, while opening to us the methods through which the forces of nature have accomplished His purpose,—while proving that there has been a plan glorious in its scheme and perfect in system, progressing through unmeasured ages and looking ever towards Man and a spiritual end,—it leads to no other solution of the great problem of creation, whether of kinds of matter or of species of life, than this:—

DEUS FECIT.

PART IV.

DYNAMICAL GEOLOGY.

DYNAMICAL GEOLOGY treats of the causes of events in the earth's geological progress.

These events include—the formation of all rocks, stratified and unstratified, with whatever they contain, from the earliest Azoic to the modern beds of gravel, sand, clays, and lavas; the oscillations of the earth's crust; the increase of dry land, elevation of mountains, and elimination of the surface-features of the globe; the changes of climate; the changes of life.

The causes or agencies, exclusive of life, that have been engaged have acted for the most part through the atmosphere, waters, and rock-material. But they are based necessarily on the general powers of Nature,—Heat, Light, Electricity, and Attraction. These fundamental powers have their universal laws,—as the law of gravitation, according to which falling bodies move; the laws of chemical attraction, according to which compounds are formed and decompositions take place; the laws of cohesion or crystallization, according to which solidification produces crystals, or a crystalline structure; the laws of heat, as regards conduction, expansion, etc., and the influence of heat on chemical changes and growth; the laws of light, as to its nature, and its action in chemical changes and growth, etc.; the laws of electricity and magnetism: all of which the geologist cannot understand too well. But the discussion of these topics belongs properly to a treatise on Physics. The laws of solidification are, however, briefly considered in this place, on account of their bearing on the structure of rocks.

In addition to the general operation of forces, there are other actions, that may be embraced under the term *climatological*, which proceed from the systematic arrangement and movement of heat, light, moisture, and electricity about the sphere (causing zones of temperature, varieties of climate, etc.), and also from the systems

of atmospheric and oceanic circulation. The general facts on these topics are briefly stated on pp. 39–48, which may well be reviewed before proceeding with the following pages. In treatises on Physical Geography these subjects may be studied to greater length by the geological student with much advantage.

The subject of dynamics, or the causes or agencies in geological history, is here treated under the following heads:—

1. Life as an agent in protecting, destroying, and making rocks.
2. Cohesive attraction, with reference especially to crystallization and the concretionary structure.
3. The Atmosphere, as a mechanical agent.
4. Water, as a mechanical agent.
5. Heat, as an agent in producing volcanic phenomena, non-volcanic igneous eruptions, metamorphism, veins, etc.
6. Movements in the earth's crust, and their consequences, including the plication of strata, origin of mountains, earthquakes, and the evolution of the general features of the globe.
7. The chemistry of rocks, or the chemical processes concerned in their origin and metamorphism, embracing a consideration of Life, the Atmosphere, Water and Heat as chemical agents. This department of the science is often called Chemical Geology. As its proper elucidation would require a large amount of space, and its study a minute knowledge of the details of Chemistry, the subject is not taken up in this Manual.

I. LIFE.

1. Protective Effects.

The protective effects of life come almost solely from vegetation.

1. Turf protects earthy slopes from the wearing action of rills that would gully out a bare surface; and even hard rocks receive protection in the same way.

2. Tufts of grass and other plants over sand-hills, as on sea-shores, bind down the moving sands.

3. Lines of vegetation along the banks of streams prevent wear during freshets. When the vegetation consists of shrubs or trees, the stems and trunks entangle and detain detritus and floating wood, and serve to increase the height of the margin of the stream.

4. Vegetation on the borders of a pond or bay serves in a similar manner as a protection against the feebler wave-action. In many

tropical regions, plants growing at the water's edge, like the mangrove, drop new roots from the branches into the shallow water, which act like a thicket of brush-wood to retain the floating leaves, stems and detritus; and, as the water shallows, other roots are dropped farther out, which are attended with the same effect; and thus they keep moving outward, and subserve the double purpose of protecting and making land.

5. Patches of forest-trees on the declivities in Alpine valleys serve to turn the course of the descending avalanche, and entangle snows that, but for the presence of the trees, would only add to its extent: and in the Alps such groves, wherever existing, are usually guarded from destruction with great care.

2. Transporting Effects.

1. Seeds are often caught in the hair or fur of animals, and thus transported from place to place.

2. Seeds are eaten by animals as food, or in connection with their food, which sometimes pass out undigested, and become planted in a new region; and, in the case of birds on their migration, they may be carried far from the place where gathered.

3. Ova of fish, reptiles, and inferior animals are supposed to be transferred from one region to another by birds and other animals. Authenticated instances of this are wanting.

4. Snails and fresh-water shells are often floated off on logs or floating plants, and sometimes are carried into estuaries or the sea, and so become mingled with marine shells.

5. Migrating tribes of men carry in their grain, or otherwise, the seeds of various weeds, and also, involuntarily, rats, mice, cockroaches, and smaller vermin. The origin of tribes may often be inferred from the species of plants and of domesticated and other animals found to have accompanied them.

3. Destructive Effects.

The destructive effects proceed either from living plants or animals, or from the products of decomposition.

1. The roots which come from the sprouting of a seed in the crevice of a rock, as they increase in size, act like a wedge in tending to press the rock apart: and, when the roots are of large size, masses tons in weight may be torn in sunder; and, if on the edge of a precipice, the detached blocks may be pushed off, to fall to its base.

2. Boring animals, like the saxicavous Mollusks, make holes of the size of the finger, or larger, in limestone and other rocks along some sea-shores. Species of *Saxicava*, *Pholas*, *Gastrochæna*, and even some Snails, Barnacles, and Echini, have this power of boring into stone.

The Teredo, Termites, and many insects, especially in the larval state, bore into wood.

3. The tunnelling of the earth made by small quadrupeds, as the mole, sometimes results in the draining of ponds, and the consequent excavation of gullies or gorges by the outflowing waters.

4. The decay of vegetation about rocks often produces carbonic acid or different vegetable acids, which become absorbed by the moisture of the soil, and thus penetrate the crevices of rocks and promote their decomposition. This is properly one of the chemical effects of life.

4. Contributions to Rock-Formations.

The capability, on the part of life, of contributing to the material of rocks depends on several considerations, of which the following are the more prominent:—

1. The conditions favoring or limiting growth and distribution,—that is, the laws of geographical distribution of living species.

2. The nature of different organic products, and the fitness of the species affording them for making fossils or rocks.

After discussing these subjects, some of the methods of contributing to rock-formations are mentioned under the heads,—

3. Methods of fossilization and concretion.

4. Examples of the formation of strata through the agency of life.

1. *Geographical Distribution.*

The subject of the geographical distribution of plants and animals, though highly important in this connection, cannot be properly treated in a brief chapter; and the student is therefore referred to treatises on this branch of science. Its general principles and bearing are all that can here be explained.

The distribution of terrestrial plants and animals is limited by different causes.

1. *Climate.*—The temperature to which each is adapted in its nature determines, within certain limits, its position in the zones between the equator and the poles, and also, under any zone, its special altitude between the level of the sea and the height of

perpetual snow. Again, the amount of moisture for which a species is made determines its position in either a moist or an arid region.

Each continent has its own characteristic climate, arising mainly out of its special combination of these two elements, temperature and moisture; and this is one source of the great diversity of life among the continents. Another point in which the climate of continents differs is the limit of extreme heat and cold. For example, North America, owing to the extent of its range from the Arctic circle to the hot tropics, is remarkable for its very wide extremes. The severe cold of winter passes over the land to the far south, destroying whatever cannot stand its power, and the summer's intense heat sweeps back again, with a similar effect: so that the continent cannot grow as many kinds of terrestrial plants or animals as that on the opposite side of the Atlantic.

2. *Continental idiosyncrasies*, or peculiarities that cannot be referred to climate. Each continent has its characteristic types of plants and animals. The Marsupials in Australia, and Edentates, or Sloth tribe, in South America, are examples; the sedate Platyrrhine Monkeys (p. 422) in South America, and the nimble frolicsome Catarrhines in Africa, are others; so also the abundance of Hummingbirds in the Occident and their absence in the Orient. Examples might be mentioned indefinitely. Moreover, the range of animal life, or that of vegetable life, has often a continental feature.

3. *Diversities of soil.*—Some plants require wet soil, others moderately dry, others arid; some rich, others sandy, others a surface of rock; some the presence of salt or a salt marsh.

The distribution of water-species is determined—First, by the character of the water, whether fresh, brackish, or salt, pure, or impure from mixed sediment; and but few species adapted for one condition survive in the other. Hence, changing a salt lake to a fresh one, or even making an addition of fresh waters which exceeds much the amount lost by evaporation (and the reverse), will dwindle or destroy the living species.

The Aral and Caspian probably made formerly one great salt sea: owing to the rivers that enter them, the living species are few. The shells are now of but twelve species, and mainly of the *Cardium* family, with *Mytilus edulis* and a *Dreissena* (Mytilus family); and only two are quoted from the Aral,—*Cardium edule* and *Adacna* (Cardium) *vitrea*. The Cardium and Mytilus families are hence capable of enduring very wide extremes in the saline condition of waters. It is interesting to note that the earliest of American bivalves (Acephals) was of the Cardium family (genus *Conocardium*), and the Mytilus family was but little later in introduction.

Secondly, by temperature and depth of water. The reef-forming corals grow in the warmer ocean-waters, in which the mean temperature for the coldest month does not fall below 68° F. The limit in depth appears to depend on the degree of light and pressure for which the species were made.

The following zones in depth have been recognized by Forbes and other observers for the convenience of marking the distribution of marine species:—

1. The *Littoral* zone,—or the tract between high and low tide level.
2. The *Laminarian* zone,—from low water to fifteen fathoms (90 feet). This zone is so named from the fucoidal sea-weed, called sometimes Tangle-weed, which is of the genus *Laminaria*, a plant especially of rocky shores.
3. The *Coralline* zone,—from 15 to 50 fathoms.
4. The *Deep-sea Coral* zone,—from 50 to 100 fathoms and beyond.

The zones of oceanic temperature are marked on the Physiographic Chart, and are explained on pages 42–44, where also facts are mentioned illustrating the geological bearing of the subject.

2. *The nature of different organic products, and the fitness of the species affording them for making fossils and rocks.*

(*a.*) *Nature of the organic products contributed to rock-formations.*—The following are some of the general facts relating to the nature of the organic products contributed by life to the rocks:—

1. Plants afford coal, fossil leaves, and fossil wood.
2. Animal remains are more or less durable according to the proportion of stony ingredients present.
3. Shells, corals, and the like contribute to rock-formations almost solely carbonate of lime, or the material of limestones.
4. Bones, in addition to carbonate of lime, contain much phosphate of lime and animal matter.
5. Diatoms, Polycystines, and spicula of Sponges afford silica.

Facts relating to the change of wood to mineral coal are mentioned on page 359. Mineral oil is another result of the decomposition of vegetation. When the carbon is only sparingly diffused through earth, it gives it a blackish color, which is lost when the material is highly heated.

Plants also afford some sulphur, potash, and soda. Carbonic acid is one of the important results of their decomposition.

Some sea-weeds are calcareous like corals, owing to their secreting lime among their sparse tissues. (See page 67.)

Animal membranes decompose and pass off for the most part as gases. Some of the carbon often remains in the bed in which it is buried, giving it a dark color. Impressions of the soft parts of animals, as of Cephalopods, have been found in rocks; but they are very rare. The tissues that penetrate shells and bones are sometimes in part retained by the ancient fossil. Two cases are

mentioned by Barrande of the conversion of the animal material within a Lower Silurian Orthoceras into *adipocere* (an animal substance having the appearance of spermaceti), and he speaks of them as the oldest *mummies* ever exhumed.

A small percentage of phosphates and fluorids is derived from decomposing animal tissues.

The Excrements of animals afford a considerable amount of phosphates, and, by decomposition, ammoniacal compounds. The latter are dissipated mostly in the air, or by solution in waters; while the phosphates are often distributed through the earth in which the animals live, or else are accumulated in beds, as in the case of guano. The excrements of the larger animals retain their form, and constitute the fossils called *Coprolites*. The amount of phosphates from the life which swarms in some muddy sea-bottoms and shores must be large. For analyses of Coprolites, see page 67.

Bones are combined with so large an amount of animal gelatine that they are the food of various animals; and this is a great source of their destruction. Again, when the animal matter decays, the bones are left very fragile, unless hardened anew by a substitution of mineral matter. In the Cartilaginous fishes, the backbone, when it fails wholly of stony material, is not found fossil, as in most fossil Ganoids.

The teeth of Vertebrates contain much less animal matter than bones, and also a coating of enamel, in which there is considerable phosphate of lime. They are therefore exceedingly durable, and the most abundant of the remains of many species. The *bony enamelled scales* of Ganoid fishes are equally enduring, differing much in this respect from the membranous scales of Teliosts.

Of *Shells and Corals* analyses are given on page 66. As the amount of animal matter present is usually very small, they have great durability.

A few shells, as those of the *Lingulæ* and *Oboli*, and probably those also of *Pteropods*, contain, like bones, a large amount of phosphate of lime (p. 68).

Traces of phosphates and fluorids are present in both shells and corals.

In a few rare species of Coral of the Gorgonia family, the stony secretions are siliceous. The Polycystines are siliceous Protozoans.

The siliceous shells of Diatoms and *spicula of Sponges* have been an important source of silica in rocks of all ages (pp. 68, 271, 482, 488). This silica is usually what is called *soluble silica* (pp. 55, 488). The index of refraction, as determined by Rood, from Diatoms is only 1.435, while that of ordinary quartz is 1.548.

The material of the sponge also is sometimes siliceous, though generally more like horn in nature. It becomes filled in with mineral matter, and in this state forms the fossil sponge. A few species of sponge have calcareous spicula.

(*b.*) The fitness of species for becoming fossilized or concreted into rocks depends in part on *their place and habits of growth.*

Water-species of plants and animals are those most likely to become fossils and contribute to rock-formations; and next those that live in marshes, or along shores or the borders of marshes. The reasons are two:—(1) Because almost all fossiliferous rocks are of aqueous or marsh origin; and (2) because organisms buried under

water or in wet deposits are preserved from that complete decomposition which many are liable to when exposed on the dry soil, and are protected also from other sources of destruction. In North America, during the Cretaceous period, the dry portions of the continent east of the Mississippi (see map, p. 489) were in all probability covered with vegetation as densely as now; and yet we have no remains of it, excepting the few in the Cretaceous beds of the Atlantic and Gulf border. We may believe also that there were numerous Mammals and birds in the forests, for Mammals began in the Triassic, and birds in the Triassic or Jurassic, but not the first specimen has anywhere been found. In the Pliocene Tertiary the species of plants and birds may have been at least half as numerous as now. Yet a few hundreds of the former and hardly a score of the latter are all that have thus far been found fossil. The natural inference from these facts is that, while we may conclude that we have a fair representation in known fossils of the marine life of the globe, we know very little of its terrestrial life,—enough to assure us of its general character, but not enough for any estimates of the number of living species over the land.

Plants and all animal matter pass off in gases when exposed in the atmosphere or in dry earth; and bones and shells become slowly removed in solution when buried in sands through which waters may percolate. Bones buried in wet deposits, especially of clay, are sealed from the atmosphere, and may remain with little change except a more or less complete loss of the animal portion. Mastodons have been mired in marshes and thus have been preserved to the present time; while the thousands that died over the dry plains and hills have left no relics.

Among terrestrial Articulates, the species of insects that frequent marshy regions, and especially those whose larves live in the water, are the most common fossils, as the *Neuropters*; while Spiders, and the insects that live about the flowers of the land, are of rare occurrence. Waders, among Birds, are more likely to become buried and preserved than those which frequent dry forests. But, whatever their habits, birds are among the rarest of fossils, because they usually die on the land, are sought for as food by numberless other species, and have slender hollow bones that are easily destroyed.

Vertebrate animals, as fishes, reptiles, etc., which fall to pieces when the animal portion is removed, require speedy burial after death to escape destruction from this source as well as from animals that would prey upon them.

Fishes in the ocean, having the means of easy locomotion through the waters, would be less liable to destruction from changes of level in the land than the Mollusks of a coast; and hence some of the sharks of the Tertiary continue through two or three epochs.

The animals generally of the ocean are little liable to extermination from changes of climate over the land; and hence *some* marine invertebrate species of the Miocene Tertiary, *many* of the Pliocene, and *all* of the Post-tertiary, con-

tinued on into the age of Man, while as regards terrestrial animal life there were in this interval many successive faunas.

(*c.*) *The lowest species of life are the best rock-makers*, especially Corals, Crinoids, Mollusks and Rhizopods; for the reason that only the simplest kinds of life can be mostly of stone and still perform all their functions. Multiplication of bulk for bulk is more rapid with the minute and simple species than with the higher kinds; for all animals grow principally by the multiplication of cells; and when single cells or minute groups of them, as in the Rhizopods, are independent animals, the increase may still be the same in rate, or even much more rapid, on account of the simplicity of structure.

3. *Methods of Fossilization and Concretion.*

In the simplest kind of fossilization there is merely a burial of the relic in earth or accumulating detritus, where it undergoes no change. Examples of this kind are not common. Siliceous Diatoms and flint implements are among them.

In general there is a change of some kind; usually, either a loss by decomposition of the less enduring part of the organic relic, with sometimes the forming of new products in the course of the decomposition, or an alteration through chemical means, changing the texture of the fossil or petrifying it, as in the turning of wood into stone.

The change may consist in a fading or blanching of the original colors; in a partial or complete loss of the decomposable animal portion of the bone or shell; a similar loss of part of the mineral ingredients by solvent waters, as of the phosphates and fluorids of a bone or shell; or a general alteration of the original organism, leaving behind only one or two ingredients of the whole; or a combining of the old elements into new compounds, as when a plant decays and changes to coal and bitumen, a resin to amber, animal matter to adipocere.

The change may be merely one of crystallization. The carbonate of lime of shells is often partly in the state of aragonite; and when so, there is usually a change in which the whole becomes common or rhombohedral carbonate of lime (calcite). Sometimes the compact condition of the original fossil is altered to one with the perfect cleavage of calcite, as often happens in encrinal columns and the spines of Echinoids.

The change often consists in the reception of new mineral matter into the pores or cellules of the fossil, as when bones are penetrated by limestone or oxyd of iron.

The change is frequently a true petrifaction, in which there is a substitution of new mineral material for the original; as when a shell, coral or wood is changed to a siliceous fossil through a process in which the organism was subjected to the action of waters containing silica in solution. In other cases, the organism becomes changed to carbonate of lime, as in much petrified wood;

and in others, to oxyd of iron and pyrites; and more rarely to fluor spar, heavy spar, or phosphate of lime.

The remains of organisms have very frequently been ground up by the action of waves or by currents of water, and thus reduced to a calcareous earth,—the concretion of which has made limestones.

When the fossils are minute, like Rhizopods and Diatoms, the simple concretion of the shells will make a solid rock, as in the case of chalk and flint (p. 488).

Ehrenberg estimates that about 18,000 cubic feet of siliceous organisms annually form in the harbor of Wismar in the Baltic; and he has also found that similar accumulations are going on in the mud of American and other harbors.

The bed of *Rhizopods* accumulating in the North Atlantic, mentioned on page 488, contains, according to Huxley, about 85 per cent. of these calcareous shells, mostly of the genus *Globigerina*, besides some siliceous Diatoms: it has probably a breadth (between Ireland and Newfoundland) of 1300 miles; and, as a similar bottom was found by Captain Dayman near the Azores, the bed has been supposed to extend southward at least 600 miles. Ehrenberg found, in a specimen examined by him, 85 species of calcareous Rhizopods, 16 of Polycystines, and 17 of Diatoms, with only a few arenaceous grains not of organic origin.

Off the Atlantic coast, from Florida north, between depths of 90 and 1500 feet, the bottom consists half or more of Rhizopod shells; and at greater depths, even beneath the Gulf Stream, to 6000 feet (as observed in lat. 28° 24′, long. 79° 13′), almost solely of them. (Pourtales.)

The siliceous shells of the microscopic *Polycystines* have been found not only in the frigid Sea of Kamtchatka (p. 488; see Amer. Jour. Sci. [2] xxii. pl. 1, for figures) and the North Atlantic, but also in the South Pacific, on both coasts of the Atlantic, in the Mediterranean, and, within the tropics, at Barbadoes in the West Indies and the Nicobar Islands in the East Indies. Ehrenberg has named 282 species from a marl-like deposit at Barbadoes, considered as Tertiary, and 100 species from the Nicobar Islands, part of them identical with those of Barbadoes.

But when the fossils are comparatively large, as with ordinary corals and shells, the intervals between them must be filled with earth of some kind, derived from the wearing action of the waters. It may be the mud or detritus from rivers or from wave-action along sea-shores. But when calcareous, it has evidently come from the wear of the shells, corals, or crinoids themselves; and hence any limestone rock made up of shells, corals, or crinoids which has the interstices thus filled in with limestone bears conclusive evidence in itself that it has not been formed in the deep ocean, but within the reach of current or wave action. Rhizopods make the only solid deep-water limestones.

The kinds of limestone made through the agency of life include soft marl or calcareous earth, chalk, compact limestone, sometimes

oolitic, of white, gray, bluish, blackish and other colors,—the dark colors mostly due to the presence of carbon from animal or vegetable decomposition.

The origin of strata through organic growth or accumulation is well illustrated in the history of peat beds and coral reefs; and this subject of life is therefore concluded by a brief description of their modes of formation.

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1. Peat Formations.

Peat is an accumulation of half-decomposed vegetable matter formed in wet or swampy places. In temperate climates it is due mainly to the growth of mosses of the genus *Sphagnum*. This plant forms a loose turf, and has the property of dying at the extremity of the roots as it increases above; and it thus may gradually form a bed of great thickness. The roots and leaves of other plants, or their branches and stumps, and any other vegetation present, may contribute to the accumulating bed. The carcasses and excrements of dead animals at times become included. Dust may also be blown over the marsh by the winds.

In wet parts of Alpine regions there are various flowering plants which grow in the form of a close turf, and give rise to beds of peat like the moss. In Fuegia, although not south of the parallel of 56°, there are large marshes of such Alpine plants, the mean temperature being about 40° F.

The dead and wet vegetable mass slowly undergoes a change, becoming an imperfect coal, of a brownish-black color, loose in texture, and often friable, although commonly penetrated with rootlets. In the change the woody fibre loses a part of its gases; but, unlike coal, it still contains usually 25 to 33 per cent. of oxygen. Occasionally it is nearly a true coal.

An analysis afforded—Carbon, 58.09, hydrogen, 5.93, oxygen, 31.37, ashes, 4.61 = 100. But there are several substances present, including three or four distinct resins and vegetable principles. It affords a number of important products by distillation, among them Paraffine. Traces of phosphates are present, arising from animal decompositions.

Peat-beds cover large surfaces of some countries, and occasionally have a thickness of forty feet. One-tenth of Ireland is covered by them; and one of the "mosses" of the Shannon is stated to be fifty miles long and two or three broad. A marsh near the mouth of the Loire is described by Blavier as more than fifty leagues in circum-

ference. Over many parts of New England and other portions of North America there are extensive beds. The amount in Massachusetts alone has been estimated to exceed 120,000,000 of cords. Many of the marshes were originally ponds or shallow lakes, and gradually became swamps as the water, from some cause, diminished in depth. The peat is often underlaid by a bed of whitish shell marl, consisting of fresh-water shells—mostly species of Cyclas and Planorbis—which were living in the lake. There are often also beds of the siliceous shields of Diatoms.

Peat is used for fuel and also as a fertilizer. When prepared for burning, it is cut into large blocks and dried in the sun. It is sometimes pressed in order to serve as fuel for steam-engines. *Muck* is another name of peat, and is used especially when the material is employed as a manure. It includes also impure varieties not fit for burning, being applied to any black swamp-earth consisting largely of decomposed vegetable matter.

Peat-beds sometimes contain standing trees, and entire skeletons of animals that had sunk in the swamp. The peat-waters have often an antiseptic power, and flesh is sometimes changed by the burial into adipocere.

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2. Coral Formations.

Coral formations are made through the growth mainly of coral zoophytes, and are confined to the warmer latitudes of the globe.

Kinds.—Coral formations, while of one general mode of origin, are of two kinds:—

1. *Coral islands.*—Isolated coral formations in the open sea.
2. *Coral reefs.*—Banks of coral bordering other lands or islands.

Distribution.—The limiting temperature of reef-forming corals is about 68° F.; that is, they do not flourish where the mean temperature of any month of the year is below 68°. The extent of the Coral seas is shown by the position of the north and south lines of 68° F. on the Physiographic Chart, as already pointed out.

The *exclusion of corals* from certain tropical coasts is owing to different causes.—(1.) The cold extratropical oceanic currents, as in the case of western South America (see map). (2.) Muddy or alluvial shores or the emptying of large rivers; for coral-polyps require clear sea-water, and generally a solid foundation to build upon. (3.) The presence of volcanic action, which, through occasional submarine action, destroys the life of a coast. (4.) The depth of water on precipitous shores; for the reef-corals do not grow where the depth exceeds 100 feet.

For the last-mentioned reason, reefs are prevented from commencing to form in the deep ocean. The notion that coral islands are rising from the depths has no support in facts: they must have the land within a few fathoms of the surface to begin upon.

Coral formations are most abundant in the tropical Pacific, where there are 290 coral islands, besides extensive reefs around other islands. The Paumotu Archipelago, east of Tahiti, contains between seventy and eighty coral islands; the Carolines, including the Radack, Ralick, and Kingsmill groups, as many more; and others are distributed over the intermediate region. The Tahitian, Samoan, and Feejee Islands are famous for their reefs; also New Caledonia and islands northwest. There are reefs also about some of the Hawaiian Islands. The Laccadives and Maldives in the Indian Ocean are among the largest coral islands in the world. The East Indies, the eastern coast of Africa, the West Indies and southern Florida abound in reefs; and Bermuda, in latitude 32° N., is a coral group. Reefs are absent from western America, except along by Panama, and mostly from western Africa, on account of the cold extratropical currents that flow towards the equator; for the same reason, there are no reefs on the coast of China. (See the Physiographic Chart.)

1. Coral Islands.

Forms.—Atolls.—The larger part of coral islands consist of a narrow rim of reef surrounding a lagoon, as illustrated in the annexed sketch (fig. 848). Such islands are called *atolls*,—a name of Maldive origin. Maps of two atolls are shown in figs. 849, 850, showing the rim of coral reef, the salt-water lake or lagoon, and the variations of form in these islands: they are never circular. The size varies from a length of fifty miles to two or three, and when quite small the lagoon is wanting, or is represented only by a dry depression.

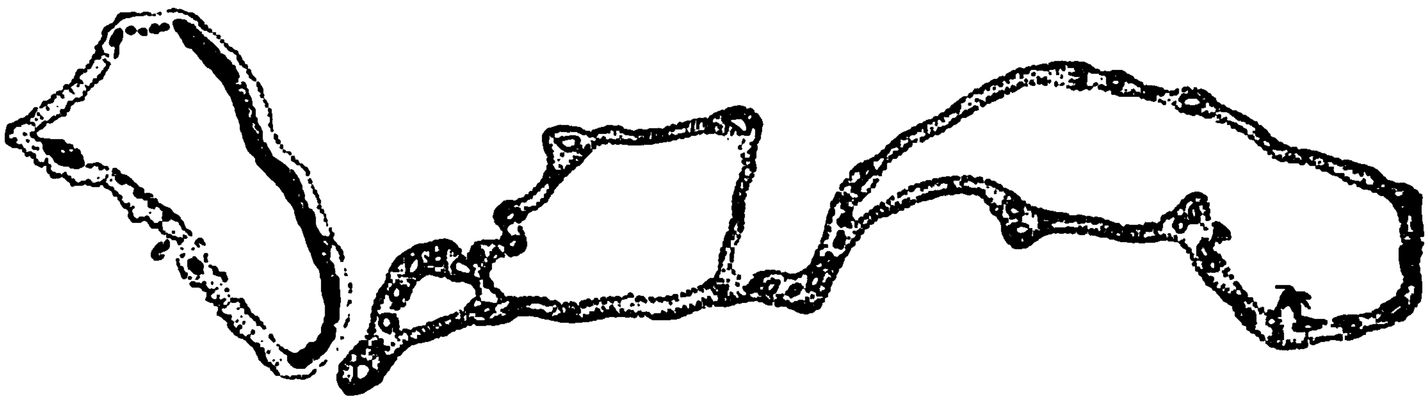
Fig. 848.

Coral island, or atoll.

The reef is usually to a large extent bare coral rock, swept by the waves at high tide. In some, the dry land is confined to a few isolated points, as Menchikoff Island, of the Caroline group (fig. 850); in others, one side is wooded continuously, or nearly so, while the other is mostly bare, or is a string of green islets, as in fig. 849, representing Apia, one of the Kingsmill Islands. The higher or

wooded side is that to the windward, unless it happens to be under the lee of another island. On the leeward side there are often chan-

Fig. 849. Fig. 850.

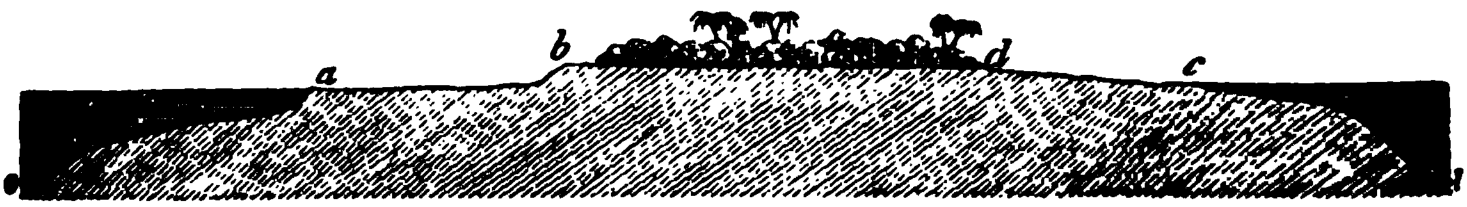


ATOLLS.—Fig. 849, Apia, one of the Kingsmill Islands; 850, Menchikoff, one of the Carolines.

nels opening through to the lagoon (*e*, fig. 849), which, when deep enough for shipping, make the atoll a harbor; and some of these coral-girt harbors in mid-ocean are large enough to hold all the fleets of the world.

Fig. 851 represents a section of an island, from the ocean (*o*) to the lagoon (*l*). On the ocean side, from *o* to *a* there is shallow water for some distance out (it may be a quarter or half a mile or more); and, where not too deep (not over one hundred feet), the bottom is covered here and there with growing corals. *a* to *b* is a platform of solid coral rock, mostly bare at low tide, but covered

Fig. 851.



Section of a coral island, from the ocean (*o*) to the lagoon (*l*).

at high, and having a width usually of about a hundred yards: there are shallow pools in many parts of it, abounding in living corals of various hues, Actiniæ (Sea-anemones), Star-fishes, Sponges, Shells, Shrimps, and other kinds of tropical life, and towards the outer margin it is quite cavernous, and the holes are frequented by crabs, fishes, etc. At *b* is the white beach, six or eight feet high, made of coral sand or pebbles and worn shells; *b* to *d* is the wooded portion of the island. The whole width from the beach (*b*) to the lagoon (*c*) is commonly not over three or four hundred

rods. At *c* is the beach on the lagoon side, and the commencement of the lagoon. Corals grow over portions of the lagoon,—although in general a large part of the bottom, both of the lagoon and the sea outside, is of coral sand.

Beyond a depth of 100 feet there are no growing corals, except some kinds that enter but sparingly into the structure of reefs, the largest of which are the *Dendrophylliæ.*

Coral reef-rock.—The rock forming the coral platform and other parts of the solid reef is a white limestone made out of corals and shells. Its composition is like that of ordinary limestones.

In some parts it contains the corals imbedded, but in others it is perfectly compact, without a fossil of any kind, unless an occasional shell. In no case is it chalk. The compact non-fossiliferous kinds are formed in the lagoons or sheltered channels; the kinds made of broken corals, on the sea-shore side, in the face of the waves; those made of corals standing as they grew, in sheltered waters where the sea has free access.

The following are the principal kinds of coral rocks:—

1. A fine-grained, compact, and clinking limestone, as solid and flint-like in fracture as any Silurian limestone, and with rarely a shell or fragment of coral. This variety is very common; and, where coral reefs or islands have been elevated, it often makes up the mass of the rock exposed to view. The absence of fossils, while the rock was evidently made out of corals and shells, is a remarkable and instructive fact.

2. A compact oolite, consisting of rounded concretionary grains, and generally without any distinct fossils.

3. A rock equally compact and hard with No. 1, but containing imbedded fragments of corals, and some shells.

4. A conglomerate of broken corals and shells, with little else,—very firm and solid; many of the corals several cubic feet in size.

5. A rock consisting of corals standing as they grew, with the interstices filled in with coral sand, shells, and fragments. In general the rock is exceedingly solid; but in some cases the interstices are but loosely filled.

Coral beach-rock.—The beach-rock is made from the loose coral sands of the shores which are thrown up by the waves and winds. The sands become cemented into a porous sandstone, or, where pebbly, into a coral pudding-stone. It forms layers, or a laminated bed, along the beach of the lagoon, and also on the sea-shore side, sloping sometimes at an angle of five or six degrees towards the water.

Formation of the coral structure.—A reef region is a plantation of living corals, in which various species are growing together,—at one place in crowded thickets, at another in scattered clumps over fields of coral sand. There is the same kind of diversity that exists

in the distribution of vegetation over the land. Some of the kinds branch like trees of small size or shrubs (*Madreporæ*); others form closely-branched tufts (*Pocilloporæ*, many *Porites*); others resemble clustered leaves (*Merulinæ*, *Manoporæ*), or tufts of pinks (*Tubiporæ*), or lichens and fungi (*Agariciæ*, etc.); others grow in hemispherical or subglobular forms (*Astreæ*, *Meandrinæ*, and some *Porites*); and others are groups of slender, brilliantly-colored twigs (*Gorgoniæ*).

When alive in the water, all these corals are covered throughout with expanded polyps, emulating in beauty of form and colors the flowers of the land.

The most common groups of reef-forming corals are the *Madrepora*, *Pocillopora*, *Porites*, *Astrea*, *Meandrina*, and *Millepora*.

1. *Madrepora.*—Corals usually neatly branched; branches with pointed extremities, each ending in a small cell or calicle; surface covered with calicles (or prominent polyp-cells) about a line in diameter.

2. *Pocillopora.*—Corals closely branched, with uniform width of interval between; branches blunt at the extremity; surface covered with angular prominences, a line or two thick, each containing several polyp-cells; spaces between the prominences also covered crowdedly with polyp-cells; texture of the coral in its interior mostly solid.

3. *Porites.*—Corals often branched; the branches blunt; surface nearly smooth, covered throughout with polyp-cells less than a line in diameter; some of the species massive, irregularly globular, and occasionally ten or fifteen feet in diameter; texture of the coral very finely cellular.

4. *Astrea.*—Corals massive, usually hemispherical, covered with radiated polyp-cells, often half an inch or more in diameter; the hemispheres sometimes fifteen or twenty feet in diameter.

5. *Meandrina.*—Corals as in the *Astrea* group in form and size, but surface covered with meandering furrows, often a quarter of an inch or more in width. Often called *brain-coral*, in allusion to the meanderings in the surface of the brain.

6. *Millepora.*—Corals branching, lamellar, massive; surface smooth; cells exceedingly minute, and in the interior of the coral divided by horizontal partitions (a characteristic called *tabulate* by Edwards).

Each of the polyp-cells in these corals corresponds to a separate animal or polyp (p. 163). In the *Madrepores*, the polyps when expanded have twelve rays or tentacles, with a diameter of an eighth to a quarter of an inch. Those of the *Pocillopores* and *Porites* are also twelve-rayed, but smaller. The *Astreas* have an indefinite number of rays or tentacles: in some species of the family the expanded flower-like polyp is an inch or more in diameter. In the *Meandrinas* the polyps coalesce in lines; there is a series of mouths along the centre of each furrow, and a border of tentacles either side.

In the *Millepores*, as stated on page 162, the animals are *Acalephs*, and not true polyps.

Another common group of corals is the *Fungia*: they have the form of broad circular or oblong disks. In many of the species the disk corresponds to a single polyp, and has a diameter in some cases of ten or twelve inches.

Corals of the different groups here mentioned grow together promiscuously at different depths up to low-tide level. The largest *Astreas*, *Meandrinas*, and *Porites*, with many *Madrepores* and other kinds, have been seen by the author constituting the *upper part* of the growing reef. At Tongatabu there were single masses of *Porites* twenty-five feet in diameter, along with *Astreas* and *Meandrinas* ten to fifteen feet. But, while these different groups do not correspond to different zones in depth, there are, without doubt, species in them which belong to the deeper waters, and others to the more shallow.

The *Porites*, and some species of the *Astrea*, *Madrepora*, and *Pocillopora* groups, continue to grow a little above low-tide level, equal to about one-third the height of the tide,—as they will endure a temporary exposure to the sun without serious injury. The *Porites* is an especially hardy group; for the corals suffer less from impurity or silt in the waters than the species of other groups.

All the reef-forming species grow within the limit of 100 feet. The *Dendrophylliæ*, and a few other kinds that grow at greater depths, contribute but little to the formation of reefs.

The polyp-corals have the power of growing indefinitely upward, while death is going on at equal rate either at the base of the structure (as in the moss of which peat is made) or through its interior, and are only stopped in upward progress by reaching the surface of the water. The hemispherical *Astreas*, many feet in diameter, although covered throughout with living polyps, may be alive to a depth of only half or three-quarters of an inch, and the huge *Porites* to a depth of less than a quarter of an inch: that is, only a thin exterior portion of the mass is really living.

Besides corals and shells, there are also some kinds of calcareous vegetation, called *Nullipores*, both branching and incrusting in form, which add to the accumulation. They grow well over the edge of the reef, in the face of the breakers, and attain considerable thickness.

Action of the waves.—The waves, especially in their heavier movements, sweeping over the coral plantations, may be as destructive as winds over forests. They tear up the corals, and, by incessant trituration, reduce the fragments to a great extent to sand; and the debris thus made and ever making is scattered over the bottom, or piled upon the coast by the tide, or swept over the lower parts of the reef into the lagoon. The corals keep growing, and this sand and the fragments go on accumulating; the consolidation of the fragmental material makes the ordinary reef-rock. Thus, by the help of the waves, a solid reef-structure is formed from the sparsely-growing corals.

Where the corals are protected from the waves, they grow up bodily to the surface, and make a weak, open structure, instead of the solid reef-rock; or, if it be a closely-branching species, so as to be firm, it still wants the compactness of the reef that has been formed amid the waves.

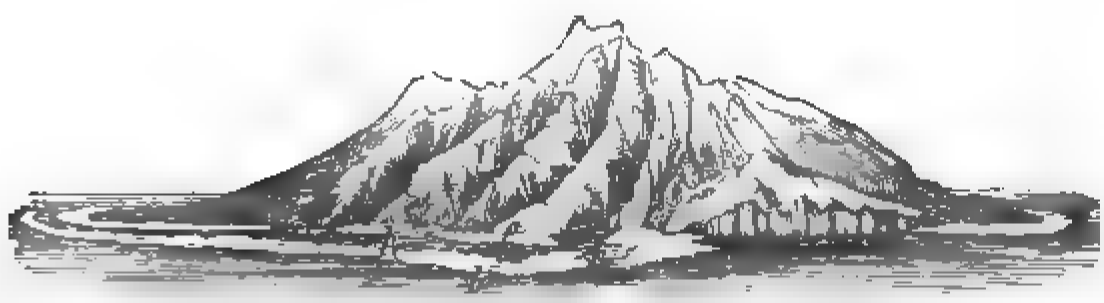
History of the emerging reef.—The growing corals and the accumulating debris reach at last low-tide level. The corals then mostly die; but the waves continue to pile up on the reef the sand and pebbles and broken masses of coral,—some of the masses even two or three hundred cubic feet in size,—and a field of rough rocks begins to appear above the waves. Next a beach is completed, and the sands, now mostly above the salt water, are planted by the waves with seeds, and trailing shrubs spring up; afterwards, as the soil deepens, palms and other trees rise into forests, and the atoll comes forth finished.

The windward side of such islands is the highest, because here the winds and waves act most powerfully; and where the leeward side of one part of the year is the windward of another, there may not be much difference between the two. The water that is driven by the winds or tides over the reef into the lagoon tends, by its escape, to keep one or more passages open, which, when sufficiently deep, make entrances for shipping.

2. Coral Reefs.

The coral reefs around other lands or islands rest on the bottom along the shores. They are either *fringing* or *barrier* reefs, according

Fig. 852.



Section of high island with barrier and fringing reefs.

to their position. *Fringing* reefs are attached directly to the shore; while *barrier* reefs, like artificial moles, are separated from the shore by a channel of water.

Fig. 852 represents an island with a fringing reef (f) and a barrier (b), and an intervening channel. Just to the right of the middle the reef is wanting, because of the depth of water, and farther to the right there is only a fringing reef. Fig. 854 is a map of an island with a fringing reef, and figs. 855–857, others with barrier reefs. At two points through the barrier reef in fig. 852 there are openings to harbors (h). Such harbors are common, and generally excellent. The channels uniting them around an island are sometimes deep

enough for ship-navigation, and occasionally, as off eastern Australia, fifty or sixty miles wide. On the other hand, they may be too shallow for boats; in which case the barrier-reefs coalesce with the fringing reefs.

The barrier sometimes becomes wooded for long distances, like the reef of an atoll; but usually the wooded portion, when there is any at all, is confined to a few islets.

The barrier and fringing reefs are formed precisely like the atoll reefs; and special explanations are needless.

The absence of reefs from parts of coasts of islands within coral-reef seas is due to several causes:—(1) to the depth of water, for corals fail if the depth exceeds one hundred feet; (2) to fresh-water streams, especially if bringing in detritus, which destroys the living corals; as such fresh waters flow over the surface of the salt, they do not prevent the corals from growing below, unless impure with detritus; (3) tidal and other currents which keep passages open, by means of the detritus they often bear along their course. These are the principal causes that prevent the harbors from becoming filled with corals and thereby destroyed.

The growth of the different parts of a reef, or its prolongation in one direction or another, depends much on the tidal and other currents that sweep through the channel or by the side of the island. As in the case of silt along other sea-shores, the coral detritus made by the waves is distributed by these currents; and hence the increase of a reef is not dependent solely on the number of growing corals over its surface, or their kinds.

Breadth of reefs.—The reefs adjoining lands have sometimes great width. On the north side of the Feejees the reef-grounds are five to fifteen miles in width. In New Caledonia they extend one hundred and fifty miles north of the island, and fifty south, making a total length of four hundred miles. Along northeastern Australia they stretch on, although with many interruptions, for one thousand miles, and often at a distance, as just stated, of fifty or sixty miles from the coast, with a depth between of fifty or sixty fathoms. But the reefs as they appear at the surface, even over the widest reef-grounds, are in patches, seldom over a mile or two broad. The patches of a single reef-ground are, however, connected by the coral basement beneath them, which is struck, in sounding, at a depth usually of ten to forty or fifty feet.

The transition in the inner channels from a bottom of coral detritus to one of common mud or earth, derived from the hills of the encircled island, is often very abrupt. Streams from the land bring in this mud and distribute it according to their courses through the channels.

Thickness of reefs.—The thickness of a coral formation is often very great. From soundings within a short distance of coral

islands, it is certain that this thickness is in some cases thousands of feet. Within three-quarters of a mile of Clermont Tonnerre, in a sounding made by Hudson, the lead struck and brought up an instant at two thousand feet, and then fell off and ran out to three thousand six hundred feet without finding bottom; and seven miles from the same island no bottom was found at six thousand feet.

The barrier-reefs remote from an island must stand in deep water. Supposing the slope of the bottom at the Gambier Islands only five degrees, we find, by a simple calculation, that the reef has a thickness of twelve hundred feet. In a similar manner, we learn that it must be at least two hundred and fifty feet at Tahiti, and two or three thousand at the Feejees.

3. Origin of the Forms of Reefs,—the Atoll and the distant Barrier.

The origin of the atoll form of reefs was first explained by the geological traveller Charles Darwin. According to the theory, each atoll began as a fringing reef around an ordinary island; and the slow sinking of the island till it disappeared, while the reef continued to grow upward, left the reef at the surface a ring of coral around a lake.

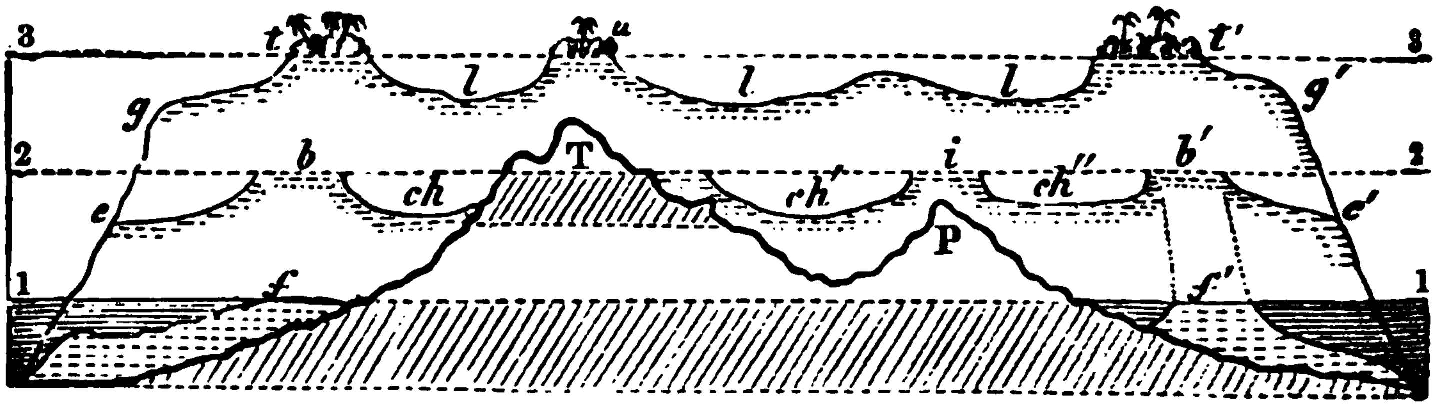
The proofs are—

1. As corals grow only within depths not greater than one hundred feet, the bottom on which they began must have been no deeper than this; and, as such a shallow depth is to be found, with rare exceptions, only around the shores of lands or islands, the reef formed would be at first nothing but a fringing reef.

2. A fringing reef being the first step in coral formations, slow subsidence would make it a *barrier*-reef.

In fig. 853 a section of a high island with its coral reefs is repre-

Fig. 853.



Section of an island bordered by a coral reef, to illustrate the effects of a subsidence.

sented, the horizontal line 1 being the level of the sea, f a section of the fringing reef on the left, and f' of the reef on the right.

The growing reef depends for its upward progress on the growth of the coral, and the waves. The waves act only on the outer margin of a reef, while the dirt and fresh water of the land directly retard the inner part. Hence the outer portion would increase the most rapidly, and would retain itself at the surface during a slow subsidence that would submerge the inner portion. The first step, therefore, in such a subsidence is to change a fringing reef into a barrier-reef (or one with a channel of water separating it from the shore). The continued subsidence would widen and deepen this channel; then, as the island began to disappear, the channel would become a lake with a few peaks above its surface; then a single peak of the old land might be all that was left; and finally this would disappear, and the coral reef come forth an atoll with its lagoon complete.

Referring again to the figure: if in the subsidence the horizontal line 2 become the sea-level, the former fringing reef *f* is now at *b*, a barrier reef, and *f′* is at *b′*, and *ch*, *ch′*, *ch″* are sections of parts of the broad channel or area of water within; over one of the peaks, P, of the sinking island, there is an islet of coral *i*: when the subsidence has made the horizontal line 3 the sea-level, the former land has wholly disappeared, leaving the barrier-reef *t*, *t′* alone at the surface around a lagoon *l l l*, with an islet, *u*, over the peak T, which was the last point to disappear.

These steps are well illustrated at the Feejees. The island Gozo (fig. 854) has a fringing reef; Augau (fig. 855), a barrier; Exploring Isles (fig. 856), a very distant barrier, with a few islets; Numuku (fig. 857), a lake with a single rock. The disappearance of this last rock would make the island a true atoll.

Figs. 854–857.

Islands of the Feejee group: Fig. 854, Gozo; 855, Augau; 856, Exploring Isles; 857, Numuku.

Whenever the subsidence ceases, the waves build up the land above the reach of the tides, seeds take root, and the reef becomes covered with foliage.

The atoll Menchikoff (fig. 850) was evidently formed, as explained by Darwin, about a high island consisting of two distinct ridges or clusters of summits, like Maui and Oahu in the Hawaian group.

If the subsidence be still continued after the formation of the

atoll, the coral island will gradually diminish its diameter, until finally it may be reduced to a mere sand-bank or become submerged in the depths of the ocean.

The rate of subsidence required to produce these results cannot exceed the rate of upward increase of the reef-ground. On page 591 some estimates are given with regard to the exceeding slowness of the movement.*

As coral debris is distributed by the waves and currents according to the same laws that govern the deposition of silt on sea-coasts, it does not necessarily follow that the existence of a reef in the form of a barrier is evidence of subsidence in that region. On page 662 the existence of sand-barriers of similar position is shown to be a common feature of coasts like that of eastern North America. In the cases of the barriers about the islands of the Pacific, however, there is no question on this point. Such barriers do not form about so small islands. Moreover, the great distances of the reefs from the shores, in many cases, and the existence of islands representing all the steps between that with a fringing reef and the true atoll, leave no room for doubt. The remoteness of the Australian barrier from the continent, and the great depth of water in the wide channel, show that this reef is unquestionable proof of a subsidence,—though it is not easy to determine the amount. Along the shores of continents the question whether a barrier coral reef is evidence of subsidence or not must be decided by the facts connected with each special case. (See Appendix E.)

Recapitulation.—The following are some of the points connected with the formation of limestone strata illustrated by coral reefs:—

1. The narrow geographical limits of coral-reef rocks at the *present* time owing to the existing zones of oceanic temperature.

2. The narrow limit in depth of the reef-making corals,—it not exceeding 100 feet.

3. The promiscuous growth of the corals over the reef-grounds.

4. The perfect compactness and freedom from fossils of a large proportion of the coral rock, although made within a few hundred feet of living corals and shells; the oolitic structure of part of this compact kind; while a variety made of broken corals cemented together is common on the seaward side of a reef, and another, made of standing corals with the interstices filled, forms where there is shelter from the ocean's waves.

5. The aid of the waves of the ocean necessary for making a

* For further information on the subject of Corals and Coral Islands, the reader may refer to the author's Exploring Expedition Report on Zoophytes, 740 pp. 4to and 61 plates in folio, 1846, and to the chapter on the Formation of Coral Reefs and Islands in his Exploring Expedition Geological Report, 755 pp. 4to and 21 pl. fol., 1849; also to Darwin on the Structure and Distribution of Coral Reefs, 214 pp. 8vo, with maps and illustrations, London, 1842; also to a memoir by Professor Agassiz.

solid limestone out of corals or ordinary marine shells, and hence their formation at great depths impossible.

6. The great extent and thickness of single reefs.

7. The action of tidal currents and those arising from the piling in of the waves during stormy weather, in keeping open channels and harbors, and determining the distribution of the coral detritus.

8. The close proximity, along shores bordered by barrier-reefs, of deposits of coral material, and deposits of river or ordinary shore detritus.

9. An exceedingly slow subsidence in progress during the growth of the corals the cause of the change of a fringing reef into a barrier, and ultimately into an atoll.

10. The necessity of this subsidence for giving great thickness to such limestones.

II. COHESIVE ATTRACTION—CRYSTALLIZATION.

The power of cohesion acting in solidification and that in crystallization appear to be identical. Snow, ice, bar-iron, trap, granite, and even solid spermaceti, are crystallized in their intimate structure. Iron and granite show it in the angular grains which make up the mass, and which may be observed on a surface of fracture; and ice, in the frosty covering of windows, and the prisms which shoot across a surface on freezing, as well as in the vertical columns into which it sometimes breaks when the ice of a pond melts in spring. Quartz exhibits it in its prismatic and pyramidal crystals (p. 55). The fact can thus be proved for all mineral solids, except it be those of a glassy nature; and even these are probably no exception to the principle that solidification is crystallization.

Crystallization is exhibited (1) in the angular solids it produces, called crystals, and (2) in a tendency to cleave or divide in one or more directions, called cleavage.

Crystals.—Some of the forms of crystals are illustrated on the early pages of this work (pp. 55–65). Crystals are formed when substances cool from fusion (as when melted sulphur cools); or solidify from solution (as in the evaporation of a solution of alum); or become condensed from the state of vapor (as in the formation of snow from vapor of water). But it is requisite usually for perfection that the process should go forward with extreme slowness, free from all disturbing causes, and with space for the crystals to

expand. Cavities in rocks are often lined with crystals, while the rock itself is but a compact mass of crystalline grains.

Long-continued heat, short of fusion, favoring a slow aggregation of the particles, sometimes produces crystals, or a crystalline structure. Heating steel to a certain temperature changes the fineness of the grains,—which is a change of crystalline texture without fusion.

Cleavage.—Cleavage is usually parallel to one or more planes or diagonals of the fundamental form.

The minerals *mica* and *gypsum* are examples of very easy cleavage. *Calcite* has easy cleavage in three directions making a fixed angle (105° 5′) with one another parallel to the faces of the fundamental rhombohedron. *Feldspar* has easy cleavage in one direction, and in another a second cleavage, a little less perfect, at right angles, or nearly so, with the first. *Quartz* has no distinct cleavage.

Cleavage in rocks.—Rocks may derive a cleavage-structure from one of the constituent minerals. Thus, mica schist cleaves into thin laminæ because of the abundance of the very cleavable mineral mica. Mica may give cleavage even to a quartz rock. Granite often has a direction of easiest fracture, due to the fact that the feldspar crystals have approximately a uniform position in the rock, bringing the cleavage-planes into parallelism.

Cleavage-structure must not be confounded with the existence of planes of fracture in rocks, called joints. Mineral coal, trap, sandstone, often break into angular blocks; but were there true cleavage, the cleavage-structure would be general along some one or more fixed directions in the mass or block, and not be limited to certain planes of fracture. Cleavage follows particular directions, but not particular planes.

The cleavage-structure of a rock like mica schist, due to a cleavable mineral, is usually called *foliation*, to distinguish this character from *slaty cleavage* (see p. 101).

Concretionary structure.—Examples of concretionary forms are given on pages 96–99. There is a general tendency in matter to concrete around centres, whether solidifying from fusion, solution, or vapors. These centres may be determined (1) by foreign substances which act as nuclei, or (2) by the circumstances of solidification, which, according to a general law, favor a commencement of the process at certain points in the mass assumed at the time. As the solidifying condition is just being reached, instead of the whole simultaneously concreting, the process generally begins at points through the mass, and these points are the centres of the concretions into which the mass solidifies.

The concretions in the same mass are usually nearly equal: hence (3) the points at which solidification in any special case begins are usually nearly equidistant. The great uniformity of size in the concretions of most beds of rock shows that foreign bodies do not generally determine the positions of the centres, although they often act as nuclei.

Basaltic columns are a result of concretionary structure formed in cooling (p. 98), in accordance with the principles just explained: each column corresponds to separate concretionary action. The size of the columns is determined by the distance apart of the points which take the lead (these points lying in the centres of the columns); and this is determined by the rate of cooling; and this, mainly, by the thickness of the mass to be cooled: the thicker the mass, the larger the columns. The cracks separating the columns from one another are due to contraction on cooling.

Iron-stone, sandstone, and clayey concretions in beds of rock, are examples in which the concreting is due to a mineral solution penetrating a stratum of clay or sand. A solution containing silica would make siliceous concretions: so also carbonate of lime in solution, or a ferruginous solution, may be the concreting agent. In either case the process is as has been explained: the distances between the centres, being first fixed in the concreting process, determine the size of the concretions, and the equality of these distances the uniformity of size.

Spherical and flattened concretions.—A mineral solution (or any liquid) naturally spreads equally in all directions through a sandy or earthy stratum, and makes, therefore, spherical concretions; but in a clayey rock it spreads laterally most rapidly, and so leads to flattened concretions. The vertical and horizontal diameters of the concretions will be to one another as the rate of spreading in the two directions.

Hollow concretions.—Flattened rings.—In a concretionary mass, the drying of the *exterior* by absorption around may lead to its concreting first. It then forms a shell with a wet unsolidified interior. The drying of the interior, since the shell is unyielding, contracts it, and consequently it becomes much cracked, as in figs. 72, 73; or, if the interior undergoes no solidification, it may remain as loose earth; or, if it solidify at the centre by the concreting process before the shell forms, or after, it may form a ball within a shell, with loose earth between.

The circumstances that would produce hollow balls among spheroidal concretions produce rings among flattened concretions or in

clayey layers. They arise from the solidification commencing first around the circumference of the concretions, and then the circle thus begun acting as a nucleus about which the concreting is continued.

III. THE ATMOSPHERE.

The following are some of the mechanical effects connected with the movements of the atmosphere.

1. *Destructive effects from the transportation of sand, dust, etc.*—The streets of most cities, as well as the roads of the country, in a dry summer day, afford examples of the drift of dust by the winds. The dust is borne most abundantly in the direction of the prevalent winds, and may in the course of time make deep beds. The dust that finds its way through the windows into a neglected room indicates what may be done in the progress of centuries where circumstances are more favorable.

The moving sands of a desert or sea-coast are the more important examples of this kind of action.

On sea-shores, where there is a sea-beach, the loose sands composing it are driven inland by the winds into parallel ridges higher than the beach, forming *drift-sand hills.* They are grouped somewhat irregularly, owing to the course of the wind among them, and little inequalities of compactness or protection from vegetation. They form especially (1) where the sand is almost purely siliceous, and therefore not at all adhesive even when wet, and not good for giving root to grasses; and (2) on windward coasts. They are common on the windward side, and especially the projecting points, even of a coral island, but never occur on the leeward side, unless this side is the windward during some portion of the year. On the north side of Oahu they are thirty feet high and made of coral sand. Some of them, which stand still higher (owing to an elevation of the island), have been solidified, and they show, where cut through, that they consist of thin layers lapping over one another; and they evince also, by the abrupt changes of direction in the layers (see fig. 61*f*), that the growing hill was often cut partly down or through by storms, and again and again completed itself after such disasters.

This style of lamination and irregularity is characteristic of the drift-sand hills of all coasts. On the southern shore of Long Island there are series of sand-hills of the kind described, extending along for one hundred miles, and five to thirty feet high. They are partially anchored by straggling tufts of grass. The coast of New Jersey down to the Chesapeake is similarly fronted by sand-hills. In Nor-

folk, England, between Hunstanton and Weybourne, the sand-hills are fifty to sixty feet high.

2. *Additions to land by means of drift-sands.*—The drift-sand hills are a means of recovering lands from the sea. The appearance of a bank at the water's edge off an estuary at the mouth of a stream is followed by the formation of a beach, and then the raising of the hills of sand by the winds, which enlarge till they sometimes close up the estuary, exclude the tides, and thus aid in the recovery of the land by the depositions of the river-detritus. Lyell observes that at Yarmouth, England, thousands of acres of cultivated land have thus been gained from a former estuary. In all such results the action of the waves in first forming the beach is a very important part of the whole.

3. *Destructive effects of drift-sands.—Dunes.*—Dunes are regions of loose drift-sand near the sea. In Norfolk, England, between Hunstanton and Weybourne, the drift-sands have travelled inland with great destructive effects, burying farms and houses. They reach, however, but a few miles from the coast-line, and were it not that the sea-shore itself is being undermined by the waves, and is thus moving landward, the effects would soon reach their limit.

In the desert latitudes, drift-sands are more extended in their effects.

4. *Dust-showers.*—Sands are sometimes taken up by whirlwinds or in heavy gales into the higher regions of the atmosphere and transported to great distances.

In 1812, volcanic ashes were carried from the island of St. Vincent to Barbadoes, 60 to 70 miles; and in 1835, from the volcano of Coseguina in Guatemala to Jamaica, 800 miles.

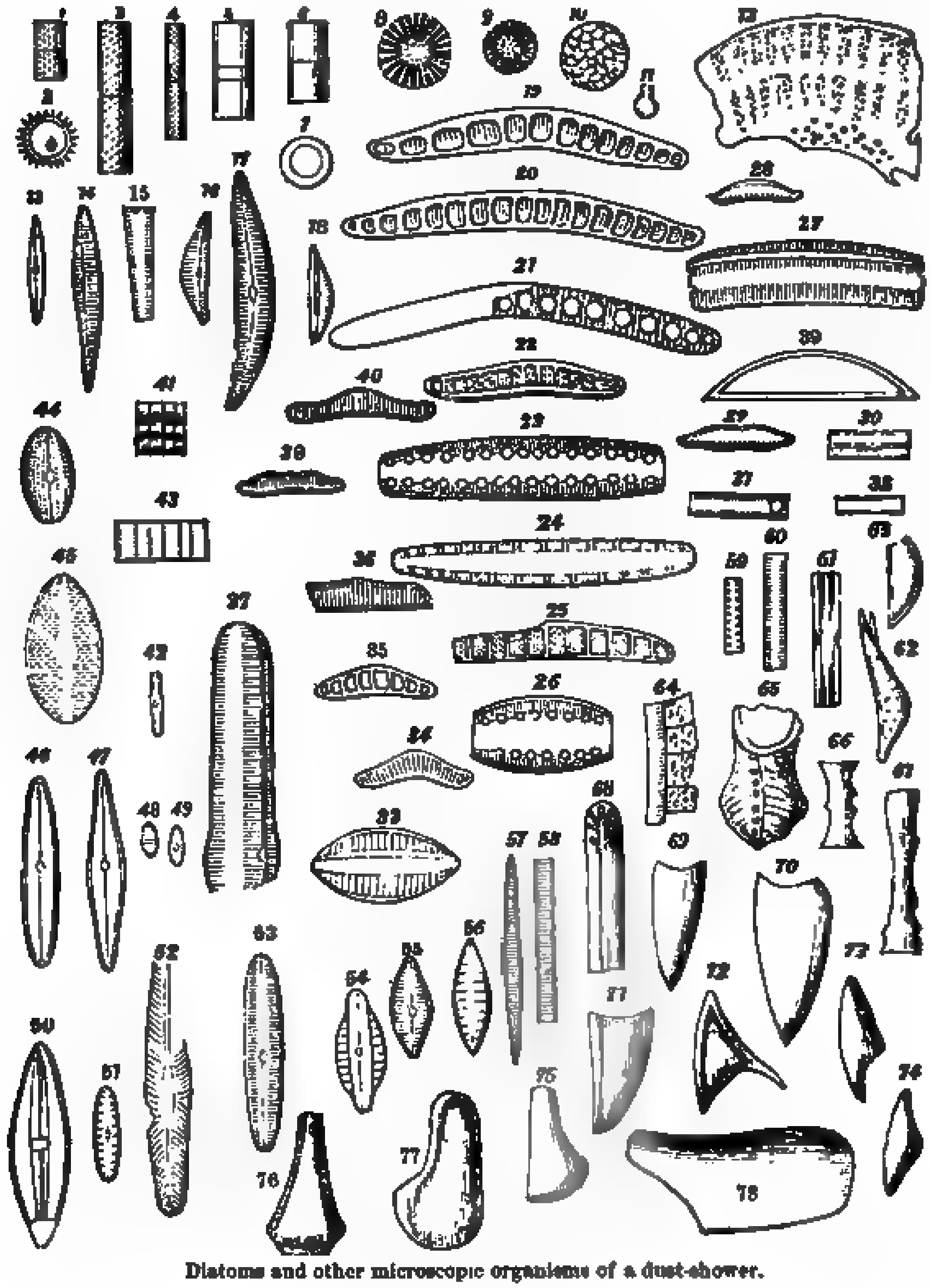
Showers of grayish and reddish dust sometimes fall on vessels in the Atlantic off the African coast, and over southern Europe; and when they come down with rain they produce "blood-rains." Ehrenberg has found that the dust of these showers is to a great extent made up of microscopic organisms.* The figures on the adjoining page represent the species from a single shower which came down about Lyons on October 17, 1846. The amount which fell at the time was estimated by Ehrenberg at 720,000 lbs.; and about one-eighth consisted of these organisms, making 90,000 lbs. of them.

The species figured by Ehrenberg include thirty-nine species of siliceous Diatoms (figs. 1-65); twenty-five of what he calls Phytolitharia, only a few of

* See his work entitled "Passat-staub und Blut-regen," 4to, 1847, and Amer. Jour. Sci. [2] xi. 372.

which are here given (figs. 66–78), besides three of Rhizopods. The names of the Diatoms are as follow :—

Figs. 1–78 (858–936).



Diatoms and other microscopic organisms of a dust-shower.

Figs. 1, 2, *Gallionella granulata* ; 3, *G. decussata* ; 4, *G. procera* ; 5, 6, 7, *G. distans* ; 8, 9, *Discoplea atmospherica* ; 10, *Coscinodiscus ?* ; 11, *Trachelomonas lævis* ;

12, *Campylodiscus Clypeus*; 13, 14, 15, *Gomphonema gracile*; 16, 17, *Cocconema cornutum* (not *gracile*); 18, *C. Lunula*; 19, 20, *Eunotia longicornis*; 21, 22, *E. longicornis*; 23, *E. Argus*; 24, *E. longicornis*; 25, *E. granulata?*; 26, *E. zebrina?* (*Argus?*); 27, *E. Monodon?*; 28–32, *E. amphioxys* (31, *cum ovario*); 33, 34, *E. gibberula*; 35, *E. zebrina?*; 36, *Himantidium zygodon?*; 37, *Eunotia gibba*; 38, *E. tridentula*; 39, *Eunotia? levis*; 40, *Himantidium Arcus*; 41, 42, *Tabellaria*; 43, *Fragilaria pinnata?*; 44, *Cocconeïs lineata*; 45, *C. atmospherica*; 46, *Navicula Bacillum*; 47, *N. amphioxys*; 48, 49, *N. Semen*; 50, *N. lineolata?*; 51, *Pinnularia borealis*; 52, *P. viridula*; 53, *P. viridis*; 54, *P. tæniata*; 55, *P. æqualis?*; 56, *Surirella Craticula?*; 57, 58, *Synedra Ulna*; 59, 60, *Fragilaria pinnata?*; 61, *Grammatophora? parallela?*; 62–65, doubtful.

A shower which happened near the Cape Verdes, and has been described by Darwin, had by his estimate a breadth of more than 1600 miles,—or, according to Tuckey, of 1800 miles,—and reached 800 or 1000 miles from the coast of Africa. These numbers give an area of more than a million of square miles.

Dust from a shower over Italy in 1803 afforded Ehrenberg forty-nine species of organisms, and another in 1813 over Calabria, sixty-four species; and the two had twenty-eight species in common.

In 1755, there was a "blood-rain" near Lago Maggiore in northern Italy, covering about 200 square leagues; and at the same time nine feet of reddish snow fell on the Alps. The earthy deposit in some places was an inch deep. Supposing it to average but two lines in depth, it would be for each square English mile an amount equal to 2700 cubic feet. The red color of the "blood-rain" is owing to the presence of some red oxyd of iron.

Ehrenberg enumerates a very large number of these showers, referring to Homer's Iliad for one of the earliest known, and asks, With such facts before us, how many thousand millions of hundred-weight of microscopic organisms have reached the earth since the period of Homer? The whole number of species made out is over 300.

The species, as far as ascertained, are not African; fifteen are South American. But the origin of the dust is yet unknown. The zone in which these showers occur covers southern Europe and northern Africa with the adjoining portion of the Atlantic, and the corresponding latitudes in western and middle Asia.

5. *Sand-scratches.*—The sands carried by the winds, when passing over rocks, sometimes wear them smooth, or cover the surface with scratches and furrows, as observed by Wm. P. Blake over granite rocks at the Pass of San Bernardino in California. Even quartz was polished, and garnets were left projecting upon pedicels of feldspar. Limestone was so much worn as to look as if the surface had been removed by solution.

6. *Changes of atmospheric pressure.*—A local change of atmospheric pressure from a passing storm has an effect on any large body of water beneath it, a diminution of pressure causing the water directly beneath to rise from the greater pressure elsewhere. A variation of one inch in the mercury column of a barometer is equivalent to 13.4 inches in a column of water. Captain J. C. Ross has observed in the Arctic regions that a change of pressure of this kind was perceptible in the tides. Observations through forty-seven days gave a variation in the water of nine inches, corresponding to two-thirds of an inch in the barometer.

The wind during storms produces sometimes an elevation of the water in the leeward part of a lake at the expense of that in the other, as has often been observed in the great lakes of North America. Great waves on the ocean and extraordinary tides on sea-coasts are other effects of the same cause. The subject of waves is treated of under the head of *Water.*

IV. WATER.

Subdivisions of the subject.

1. Fresh waters; including especially Rivers and the smaller Lakes.

2. The Ocean; including the larger lakes, whether salt or fresh-water,—the general facts being similar, excepting such as depend on the tides, and the kind and density of the water.

3. Frozen waters, or Glaciers and Icebergs.

1. FRESH WATERS.

The *Superficial* waters and the *Subterranean* may be separately considered.

A. SUPERFICIAL WATERS, OR RIVERS.

1. General Observations on Rivers.

1. *Water of rivers.*—The fresh waters of the land come from the vapors of the atmosphere, and these are largely furnished by the ocean. They rise into the upper regions of the atmosphere, and, becoming condensed into drops, descend about the hills and plains, and so begin their geological work,—gravity being the moving power.

The amount of water in a river depends on (1) the extent of the

region it drains; (2) the amount of rain, mist, or snow of the region; (3) its climate,—heat and a dry atmosphere increasing the loss by evaporation; (4) its geological nature,—absorbent and cavernous rocks carrying off much of the water; (5) its physical features,—a flat, open, unwooded country favoring evaporation.

The annual discharge of the Mississippi River averages nineteen and a half trillions (19,500,000,000,000) of cubic feet, varying from eleven trillions in dry years to twenty-seven trillions in wet years. This amount is about *one-quarter* of that furnished by the rains. This river is 3500 feet wide at St. Louis, 4000 off the Ohio, and about 2500 at New Orleans.

The mean annual discharge of the Missouri River is about three and three-quarter trillions, or *fifteen-hundredths* of the amount of the rains over the region. The corresponding amount for the Ohio is five trillions, which is *one-quarter* the amount of rain. (Humphreys & Abbot.)

The rivers of some dry countries, as Australia, are great floods in the rainy seasons and a string of pools in the dry.

2. *Amount of pitch or descent in rivers.*—The average descent of large rivers, excluding regions of cascades, seldom exceeds twelve inches to a mile, and is sometimes but half this amount.

The following facts on this point are from Humphreys & Abbot's Report on the Mississippi Basin. The descent per mile is given in inches; L. stands for the *low-water* slope, and H. for the *high-water* slope.

		L.	H.
Mississippi R.	Mouth to Memphis (855 m.)	4.82 in.	5.23 in.
"	Mouth to Cairo at mouth of Ohio (1088 m.)	6.94	5.96
"	Above the Missouri to source (1330 m.)	11.74	
Missouri R.	Mouth to St. Joseph (484 m.)	9.24	
"	St. Joseph to Sioux City (358 m.)	10.32	
"	Sioux City to Fort Pierre (404 m.)	12.12	
"	Fort Pierre to Fort Union (648 m.)	13.20	
"	Fort Union to Fort Benton (750 m.)	10.56	

Fort Benton is 2644 miles above the mouth of the Missouri. The whole Missouri from its highest source, a distance of 2908 miles, has a descent of about 6800 feet,—or 28 inches per mile.

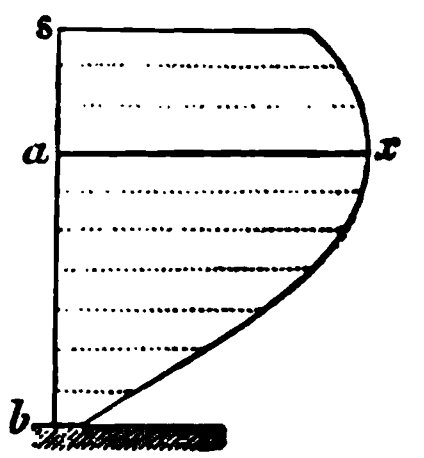
During floods, the pitch of the surface of a stream is increased in amount and uniformity. (1.) The waters are higher in the interior of the country than near the ocean, because of the easy discharge through its mouth. (2.) Owing to the height of the waters, which often cover the banks, the course loses some of its minor bends, and the whole distance is therefore less. (3.) The inequalities of slope between the still water and more rapid portions mostly disappear. But when the river runs through a narrow, rocky gorge

the waters above the entrance of the gorge are partially held back, and have less slope during freshets than at low water; and consequently the pitch through the course of the gorge is increased.

3. *Flow of a stream.*—The above causes affect directly the velocity of the stream, as this varies with the pitch and depth of water. The sudden expansion in size and depth of a river-channel, as when a lake intervenes, also affects the velocity, often producing seemingly a state of nearly perfect quiet. The water-level becomes for the interval nearly horizontal. R. Bakewell, Jr., accounts for the quiet at the whirlpool in the rapids below the Falls of Niagara on the ground of the great increase of depth and the abrupt expansion in breadth.

The movement of a stream is most rapid near the surface above the line of deepest water. The bottom, sides, and air retard by friction the layer in contact with them, and other adjoining layers are retarded through the cohesion between the particles of the water. The velocity is greater the less the extent of the upper (or air) and bottom surfaces,—the surfaces of friction. When two streams unite, the waters have the surfaces of friction of one stream instead of two, and there is consequently an increased rate of flow; besides, owing to the greater velocity, the united waters do not occupy a space equal to the sum of those which they occupied before the union.

Fig. 937.



The velocities at different depths from the surface to the bottom being represented by parallel lines drawn from a given base-line, if the extremities of these lines be connected the curve obtained is a parabola whose axis is parallel to the water's surface and may be some distance below it, and whose abscissæ vary as the velocities,—a principle first established by Humphreys & Abbot. The form of the parabola changes with the changing depth and other conditions of a river. Fig. 937, from the Report of these authors, shows the curve deduced for the Mississippi at mean height, from observations made in 1851 at Carrollton and Baton Rouge: *s* is the surface; *b*, the bottom; *a x*, the axis of the parabola. They give other figures, representing the curve for low and high water, and others also as deductions from each set of observations. The axis, or line of greatest velocity, is nearest the surface at low water. For the methods of experiment in determining the velocities, and for all details on this important subject, and mathematical formulas connected with it, reference should be made to the admirable "Report on the Physics and Hydraulics of the Mississippi River," by Captain Humphreys and Lieutenant Abbot, 4to, 1861, based upon surveys and investigations made under acts of Congress, directing the topographical and hydrographical survey of the Delta, &c.

4. *Force of running water.*—According to Hopkins, the force of running water varies as the sixth power of the velocity: so that doubling the rate increases sixty-four times the force. If a stream running ten miles an hour would just move a block of five tons' weight, then a current of fifteen miles would move a similar block of fifty-five tons; one of twenty miles, a block of three hundred and twenty tons; while a current of two miles an hour, or three feet per second, would move a pebble of similar form only a few ounces in weight; at one foot per second, gravel; at six inches, fine sand; at three inches, fine clay.

Other characteristics of rivers are brought out in the following pages.

2. Mechanical Effects of Rivers.

The mechanical effects of fresh waters are,—

1. Erosion, or wear.
2. Transportation of earth, gravel, stones, etc.
3. Distribution of transported material, and the formation of fragmental deposits.

1. Erosion.

1. *General statement of the effects of erosion.*—The effects of erosion are seen, *first*, in the imprint of the falling rain-drop,—a trifling matter to most eyes, but not so to the geologist; for it remains among the records of the earliest and latest strata to show that it rained then as now, and to teach us where the lands at the time lay above the ocean. It is, therefore, a part of the markings in which the geographical history of the globe is registered.

Second. The gathering drops make the rill, and the rill its little furrow; rills combine into rivulets, and rivulets make a gully down the hill-side; rivulets unite to form torrents, and these work with accumulating force, and excavate deep gorges in the declivities. Other torrents form in the same manner about the mountain-ridge, and pursue the same work of erosion until the slopes are a series of valleys and ridges, and the summit a bold crest overlooking the eroding waters.

2. *Progress of erosion in the formation of valleys or river-courses.*—The mist and rains about the higher parts of mountains are usually the main source of the water. As the first-made streamlets are gathering into larger streams through the course of the descent, and are largest below, the torrent has its greatest force towards the bottom of the declivity, and there the valley first takes shape and size.

Let A B (fig. 938) represent a profile of a declivity. As the ero-

sion goes on, a valley is formed along *l m*, on the principle just stated, so that the course of the waters on the profile corresponds to A *l m*. At *m*, the most of the descent of the declivity is made; the waters have, therefore, but little eroding power at bottom, and they flow off at a small angle to B, along the line *m* B. At *m*, moreover, the stream, ceasing to erode much at bottom, commences to erode laterally during freshets, undermining the cliffs on either side when the rocks admit of it, thus widening the valley and making a "flood-plain" or "bottom-lands" through which the stream when low has its winding channel.

The river, in this state, consists of its *torrent-portion*, A *m*, and its *river-portion*, *m* B. Along the former a transverse section of the

Fig. 938.

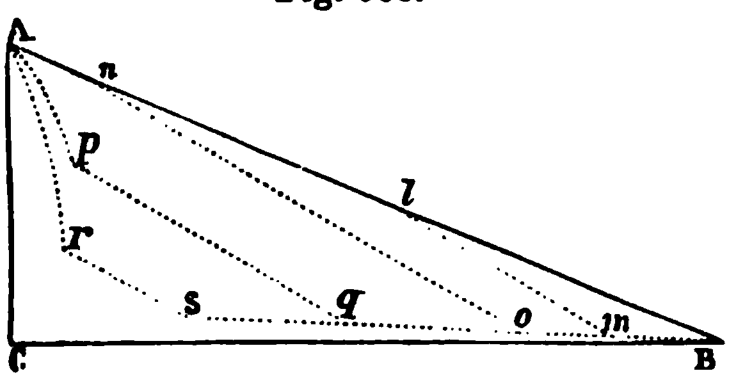
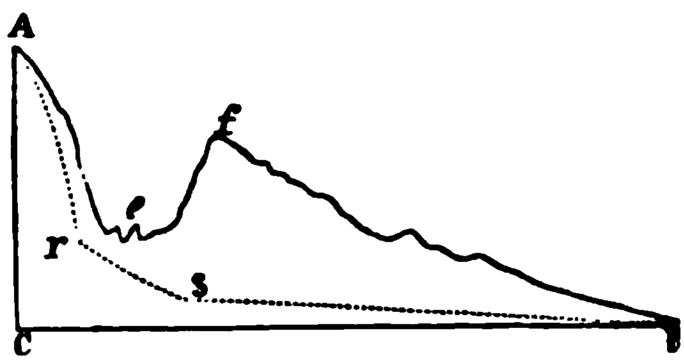


Fig. 939.



valley is approximately V-shaped, and along the latter nearly U-shaped, or else like a V flattened at bottom. The river-portion usually exhibits, even in its incipient stages, its two prominent elements,—a *river-channel*, occupied by the waters in ordinary seasons, and the *alluvial flat* or *flood-ground*, which is mostly covered by the higher freshets. The two go together whenever the course of the stream is not over and between rocks that do not admit of much lateral erosion and a widening thereby of the river-valley.

In the farther progress of the stream, A *n o* becomes the *torrent-portion*, and *o* B the *river-portion*. Later, the valley commences from the summit A.

As the waters continue their work of erosion about the summits, where the mists and rains are most abundant and often almost perpetual through the year, the next step is the working down of a precipice under the summit or towards the top of the declivity, making the course of the waters A *p q* B, and, later, A *r s* B. The stream in this state has (1) a *cascade-portion*, and (2) a *torrent-portion*; besides (3) its *river-portion*. The precipices thus formed are sometimes thousands of feet in height; and the waters often descend them in thready lines to unite below in the torrent. The mountain-top is chiselled out by these means into a narrow, crest-like ridge. Each separate descending rill frequently makes its own recess in the

side of the precipice, and together they may face it with a series of deep alcoves and projecting buttresses.

The next step in the progressing erosion is the wearing away of the ridge that intervenes between two adjoining valleys. This takes place about the higher portions nearest the mountain-crest, where the descending waters are most abundant. Gradually the ridge thins to a crest, and finally becomes worn away for some distance, so that two valleys (or more by the wear of more ridges) have a common head. In fig. 939, A *r s* B represents the course of the stream, as in fig. 938; and *A e f* B the eroded ridge, which has lost at *e* much of its height. The erosion, continuing its action around the precipitous sides of the united head of the valleys, may widen it into a vast mountain amphitheatre.

This is theoretically the history of valley-making, and the actual history when the course is not modified by the structure of the rocks.

A model of this system of erosion is often admirably worked out in the earthy slopes along a road-side,—the little rill having its cascade-head, then its torrent-channel, and below its flat alluvial plain with the winding rill-channel; some of the ridgelets in their upper parts worn away until two or more little valleys coalesce; then in some cases the head of the coalesced valleys widened into an amphitheatre, and the walls fluted into a series of alcoves and buttresses.

The system is illustrated on a grand scale among the old volcanic islands of the Pacific, where the slope of the rocks at a small angle (5 to 10 degrees) from a centre has favored a regular development. On Mount Kea (Hawaii), nearly 14,000 feet high, the valleys extend about half-way to the summit, having made only this much progress upward since the volcano became extinct. On Tahiti, the old mountain is reduced to a mere skeleton. The valleys lead up to amphitheatres bounded by precipices of 2000 to 3000 feet, directly under the peak; and the ridges between the valleys, though 1000 to 2000 feet high, are reduced in the interior to mere knife-edges, impassable except as they are balustraded by shrubbery; and in some cases, adjoining the central heights, they are worn down to a low wall or pinnacled crest, partially separating two of the valleys. The traveller ascending one of the valleys along the bed of the stream finds himself at last at the base of inaccessible heights, with numberless cascades before him and a range of buttressed walls of remarkable grandeur.* Something of this buttressed character of precipices is seen in fig. 941.

The nature of the rocks causes modifications in these results. If there are harder beds at intervals in the course of the stream, or any impediment to even wear, the impediment becomes the head of a waterfall and precipice, whose height increases rapidly from the

* See the Author's Expl. Exped. Geol. Rep., p. 290, and Amer. Jour. Sci. [2] ix. 48, and 289.

force of the falling waters, until some other similar impediment below limits the farther erosion. Thus many waterfalls and rapids are made in the cascade-portion of a stream, and they are not absent from the river-portion. Another effect of this cause is that the stream is set back for some distance above a waterfall, and has in this part more or less extensive flood-plains.

If the rocks are in horizontal strata and easily worn, the waters work rapidly down to the level of the river-portion, so that the cascade and torrent portion are each short or are hardly distinguishable. The streamlets descending the walls of such soft rocks will easily widen the head of the valley into an extensive amphitheatre; while in the farther course of the valley, beyond the limit of the rainy region, the valley may be only a narrow gorge, hundreds, or perhaps thousands, of feet deep. Here in these depths the stream meanders through a ribbon of alluvial land, rich in verdure at one season, and in others mostly flooded. Examples of all these peculiarities of river-valleys might be described from among the rivers of North America, especially the streams of the Mississippi valley and those of the slopes of the Rocky Mountains, where the rocks are in general stratified, and usually not far from horizontal in position.

The remarkable cañon of the Colorado, between the meridians of 111° and 115° W. long., has already been partly described on p. 569 from the account furnished by Dr. Newberry. The principal facts are these:—A length of 300 miles, and through the whole nearly vertical walls of rock, 3000 to 6000 feet in height; these rocks limestone and other strata of Carboniferous age, others of older Palæozoic, and below these generally the solid granite, making from 500 to 1000 feet of the gorge; and in some places the granite rising in pinnacles out of the waters of the stream; finally, all the tributaries or lateral streams with similar profound gorges or chasms. The view represented in fig. 940 was taken at the junction of the Colorado and the Green Rivers, near the meridian of 113½°. It shows well the narrow and profound chasm in which the waters of the Colorado flow, although not doing justice to the depth, which at this place is about 3000 feet. Some distance up the stream the two rivers come together, the Colorado from far to the right, and Green River from the left; and everywhere over the great plain there are the profound lateral chasms or side-cañons of the tributaries.

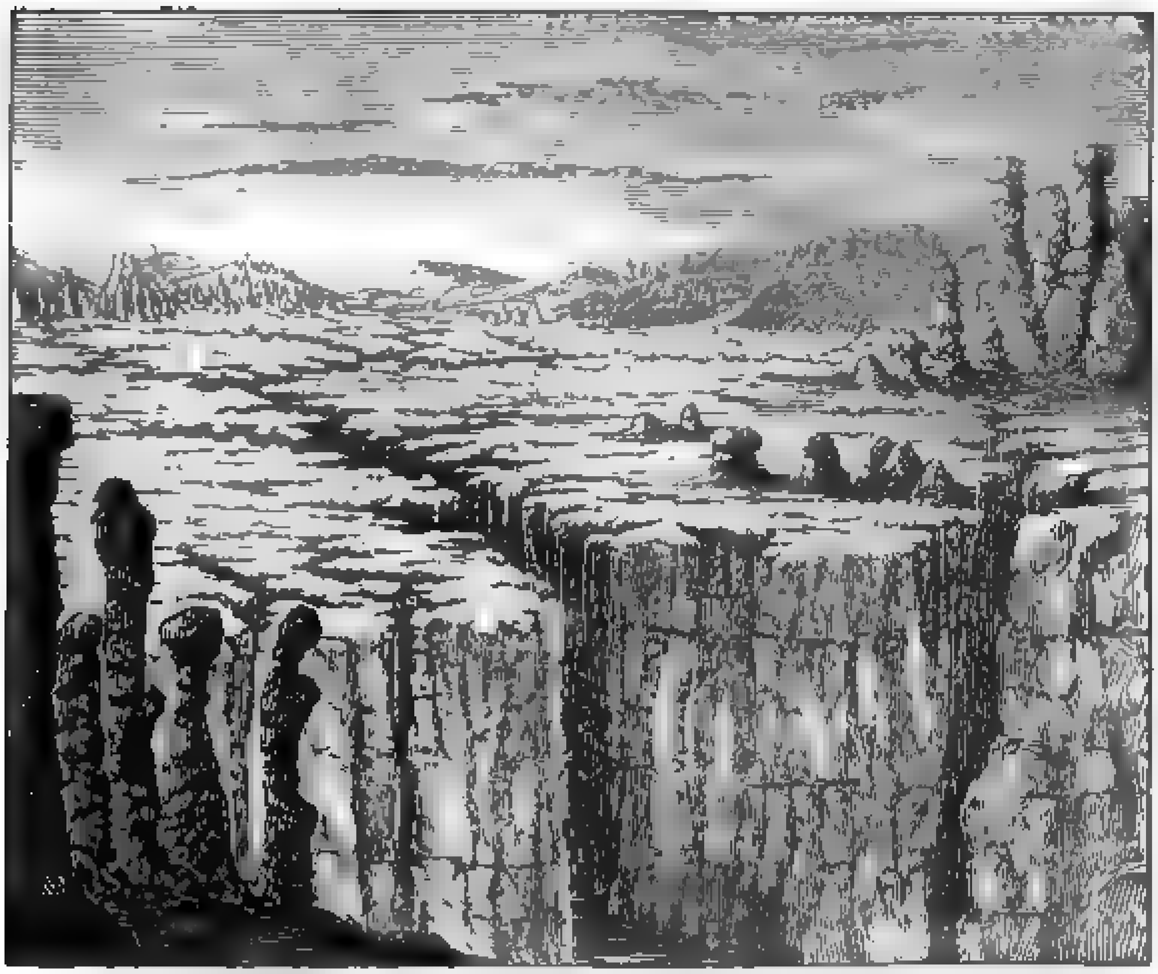
Fig. 941 is another view from the same remarkable region, illustrating especially the side-cañons. It is from the excellent Report of Lieutenant J. C. Ives, the commander of the expedition with which Dr. Newberry was connected, and is one among many views equally grand and instructive given in this Report.

Newberry attributes these profound gorges, and beyond doubt correctly, to erosion, each stream having made its own channel. The cliffs are so high that in general no undermining can set back the walls far enough to allow of alluvial

plains along the bottom, even when the water is not too rapid; and when a channel is cut in granite, lateral wear is always small.

In the more distant part of fig. 940 there is a higher level of rock,—the

Fig. 940.



Cañon of the Colorado near its junction with Green River.

overlying gypsiferous red sandstone (Triassic or Jurassic, p. 417). It is in isolated tables, and in some places in columns, needles, and towers, the greater part of the formation having been swept off by erosion, due partly at least to fresh waters. Still farther to the east, beyond the range of the view, another still more elevated level is formed by Cretaceous strata: the existing surface-features are similar to those of the older red sandstone.

Owing to the rapid increase of ratio in the power of running water attending increase of velocity, the eroding action of water during freshets becomes immense.

Many examples are on record of gorges hundreds of feet deep cut out of the solid rock by two or three centuries only of work Lyell mentions the case of the Simeto in Sicily, which had been dammed up by an eruption of lavas in 1603. In two and a half

Fig. 941.

Side-cañons of the Colorado.

centuries it had excavated a channel fifty to several hundred feet deep, and in some parts forty to fifty feet wide, although the rock is a hard solid basalt. The larger part of the valleys of the world are formed entirely by running water. At Tahiti, where they are one to three thousand feet deep, they all terminate before reaching the sea, showing that they have been formed while the land has stood, as now, above the ocean.

The *windings* of the stream in large alluvial flats are most numerous where the current is exceedingly slow; for slight obstacles change the course, throwing the current from one side to the other. Between the mouth of the Ohio and the Gulf of Mexico (head of the Passes), the length of the Mississippi is 1080 miles, and the actual distance in a straight line about 500 miles.

Pot-holes are incident to the process of erosion when the waters flow in rapids over a bed of hard rocks. Any obstacle causes the waters to move in a whirl and carry around pebbles or stones, and, by this grinding process, circular pits or basins are worn in the solid rock. The "Basin" in the Franconia Notch (White Mountains) is a pot-hole in granite, fifteen feet deep and twenty and twenty-five feet in its two diameters. There are many pot-holes at Bellows Falls, on the Connecticut; others on the White River, in the Green Mountains, and elsewhere. One of those on the White River is fifteen feet deep and eighteen in diameter; another, twelve feet deep and twenty-six in diameter.

3. *Flood-plain.*—The facts connected with the flood-plains derive a special importance from their bearing on the subject of terraces.

The breadth of the flood-plain of a stream depends (1) on the general features of a country, and (2) on the stream's capability of encroaching laterally on the hills either side. In some cases this breadth is ten to twenty miles, and even fifty miles along such rivers as the Sacramento. In the case of these broad plains, the valley is seldom one of erosion simply, but generally a *synclinal* trough. When a stream crosses a series of synclinal valleys, the flood-plain generally expands as it enters each, and contracts at the passage from one to the other.

The surface of a flood-plain is only approximately flat. (1) The margin along a stream is often higher than the part back of it; (2) some portions are frequently within the reach of only the very highest freshets; (3) others are quite low, and are sometimes occupied by ponds of water or lagoons fed from the river by percolation through the soil. The variation of height from these sources is often equal to two-thirds of the whole average height of the flood-plain above the river. The surface is sometimes changed much in height during freshets, by the wearing away of one part and the increase of others.

The height and pitch of the flood-plain are essentially that of the stream at flood-height, and will, therefore, be affected by the causes mentioned on page

633. It will be comparatively low towards the ocean. It will be diminished by any abrupt expansion of the river-valley, by which the waters spread laterally to great distances and consequently have diminished vertical height. Conversely, the height will be increased by a narrowing of the valley, and especially before the entrance of a contracted gorge.

While, therefore, there is a general parallelism between a stream at low water and its flood-plain, there are wide variations from this parallelism.

The occurrence of waterfalls in the course of a stream causes the flood-plain above to stand at a higher level than that below, equal at least to the height of the fall, and somewhat above this height if the fall occurs in a gorge, which would set the waters back during a flood.

If the erosion of some thousands of years or less deepen the bed of a stream fifty feet, the flood-plain would sink correspondingly to a lower level; and thus, in the lapse of time, without other geographical change than the one mentioned, a *terrace* would be formed, some portion of the old plain being left, as would naturally happen, at its former height. If a waterfall were gradually obliterated, the flood-plain would undergo a corresponding change. If the barrier that caused the existence of a lake along a river were removed, there would be a sinking of the river's channel, and a sinking by erosion also of the flood-plain. If from any cause—as a mountain-slide—a barrier were thrown across a stream and a lake made, the flood-waters would stand at a correspondingly higher level than before, and would spread more widely, making new flood-plains above the former level. If the progressing erosion be very much less on one part of a stream than on another (from the nature of the country, or that of the rocks, etc.), the changes in the level of the later flood-plain would have the same differences. Small streams would, of course, sink their channels by erosion less than the large ones to which they are tributary, provided the pitch be the same and the bed similar in material; and even a large pitch will not often compensate for a very great difference in the amount of water.

These are changes in the flood-plain which may take place from the ordinary incidents to which rivers are exposed.

Finally, if a continent undergo an elevation, the pitch of the river is increased and new erosive power is given it; and with the progress of the elevation new flood-plains would form at lower and lower levels. This subject is already explained at length on page 555. The only case in which the river would not have a greater pitch after such an elevation is when the coast-region added by the elevation slopes seaward at the same angle with that of the stream before the elevation, or at a less angle than this.

2. Transportation by rivers.

The *transporting power* of running water is mentioned on page 635.

The *materials transported* are (1) stones, pebbles, sand, and clay; (2) logs and leaves from the forests, and sometimes trees that have been torn up or dislodged by the current; (3) mollusks, worms, insects, attached to the logs or leaves; (4) occasionally larger ani-

mals that have been surprised and drowned by freshets, or bones that have been exhumed by the waters.

The fine earthy material deposited by streams, or their *sediment*, is called *silt*, or *detritus*. In accordance with the law with regard to the transporting power of water, stones and pebbles make the bed of rapid streams, and in general earth or silt where the current is slow.

The amount of transportation going on over a continent is beyond calculation. Streams are everywhere at work, rivers with their large tributaries and their thousand little ones spreading among all the hills and to the summits of every mountain. And thus the whole surface of a continent is on the move towards the oceans. In the rainy seasons the streams increase immensely their force. Streamlets in the mountains that are almost dry in summer become destructive torrents during the rains.

The *process of transportation is also one of wear*. The stones are reduced to sand and fine earth by the friction. The silt is nothing but the coarse material of the upper waters ground up. The soil of the plains and sand of the sea-shore are the pulverized rocks of the mountains,—running waters being the moving-power, and the mutual friction of stone upon stone, or grain of sand upon grain, the means of grinding. The word *detritus* means *worn out*, and is well applied to river-depositions. On large rivers, stones and pebbles disappear from the alluvium long before they reach the sea, and partly for the reason here mentioned. The process is sometimes aided by the partial decomposition of the rocks.

The *amount of silt* carried to the Mexican Gulf by the Mississippi, according to the Delta Survey under Humphreys & Abbot, is about 1-1500th the weight of the water, or 1-2900th its bulk; equivalent for an average year to 812,500,000,000 pounds, or a mass one square mile in area and 241 feet deep.

The following table contains the ratio of sediment to water by weight, as obtained by the Delta Survey and also the results of other investigations. It is from Humphreys & Abbot's Report (p. 148):—

	Ratio.	Time.
Mississippi R., at Carrollton, by Delta Survey,	1 : 1808	12 mos., '51–'52.
" " "	1 : 1449	12 mos., '52–'53.
" Columbus, "	1 : 1321	9 mos., '58.
" Mouths, by Mr. Meade,	1 : 1256	2 mos., '38.
" " " Mr. Sidell,	1 : 1724	1838.
" Various places, Prof. Riddell,	1 : 1245	14 days, summer of 1843.
" New Orleans, "	1 : 1155	35 days, summer of 1846.
Rhone, at Lyons, by Mr. Surell,	1 : 17000	1844.
" " Arles, Messrs. Gorsse & Subours,	1 : 2000	4 mos., 1808–9.
" in Delta, Mr. Surell,	1 . 2500	
Ganges, by Mr. Everest,	1 : 510	12 mos.

The bulk may be calculated by taking 1.9 as the specific gravity of the material. The total annual discharge of sediment from the Ganges has been estimated at 6,368,000,000 cubic feet.

Besides the material held in suspension, as these authors observe, the Mississippi *pushes* along into the Gulf large quantities of earthy matter; and, from observations made by them, they estimate the annual amount thus contributed to the Gulf to be about 750,000,000 cubic feet,—which would cover a square mile 27 feet deep; and this, added to the 241 feet above, makes the total 268 feet.

The quantity of wood brought down by some American rivers is very great. The well-known natural "raft" obstructing Red River had a length, in 1854, of thirteen miles, and was increasing at the rate of one and a half to two miles a year, from the annual accessions. The lower end, which was then fifty-three miles above Shreveport, had been gradually moving up stream from the decay of the logs, and formerly was at Natchitoches, if not still farther down the stream. Both this stream and others carry great numbers of logs to the delta.

3. Distribution of transported material.

1. *Alluvial formations in river-valleys.*—Alluvial formations cover usually a broad area on one or both sides of a river. They are in general the basis of the flood-plain; and the features of this plain, as already described, are the exterior characteristics of the alluvium. They are made from the material brought down by the stream, especially during freshets, and consist of earth and clay, sometimes thinly laminated, with some beds of pebbles, and occasionally stones. These coarser beds are most abundant along the upper portions of the stream, while towards the mouth—particularly in the case of large rivers—the material may be wholly a fine silt.

Logs and leaves are in some cases distributed through alluvial deposits, but always sparingly; for they are mostly destroyed by wear or by decay. They rarely, if ever, accumulate in beds fitted for making coal, being widely scattered by the currents. Fresh-water and land shells are occasionally found in the beds. Remains of other animals seldom escape destruction, unless buried in a lagoon-portion of the flood-plain.

As the range of height within which river-waters can work has narrow limits, the thickness of the alluvial formations made by a stream, in any given condition of it, is necessarily small. Even the whole of the river-flat above the level of its bottom may not have been deposited by the river in its existing state; for the channel

and flood-plain may be excavated in the alluvium of an earlier period, so that the upper surface alone may be of recent origin (p. 550). If, however, the land were undergoing a very slow subsidence, which should diminish the pitch of the stream, a deposition of detritus would take place which would raise both its bed and flood-plain, and the thickness might thus go on increasing as long as the subsidence continued.

The deposition of detritus which takes place along the course of a river usually raises the borders of the channel above the general level of the flood-plain. Along the Lower Mississippi, the pitch of the plain away from the river amounts, on an average, to seven feet for the first mile. (Humphreys & Abbot.)

The earthy alluvium which is formed by a slow deposition of detritus consists of very thin even layers. A vibration or wave-movement in any waters in which a sediment is falling tends to arrange that sediment in layers, each layer corresponding to a wave, and showing by a difference of texture in its under and upper portions the progress of the wave. In the case of accumulations from a rapid deposition or pressing forward of material, the lamination is often wanting.

The pebbles or stones forming beds in the alluvium are brought in by the upper waters and lateral tributaries during floods. The course of a tributary across the river-plain is often marked by a wide bed of stones. The sweep of a freshet over the earthy flood-plain may carry away the finer earth and leave a surface of pebbles. The bank of a river struck by a strong current may in a similar way be made pebbly, while the opposite is muddy or has a sand-bank forming from the earth carried across.

Still other irregularities result from changes in the river-channel. The transfer of material from one side of a stream to the other ends often in making a long bend, and finally in cutting off the bend and turning it into an island, and ultimately into a part of the mainland by the filling up of the old channel.

The islands in the large rivers are also very unstable. In the Mississippi, as Humphreys & Abbot observe, they often begin in the lodging of drift-wood on a sand-bar; this causes the accumulation of detritus; a growth of willow succeeds; the height of the alluvium still increases, until finally the island reaches the level of high water, or rises even above it, and becomes covered with a growth of cotton-wood, willow, etc. By a similar process, the island may be united to the mainland; or, "by a slight change of direction of the current, the underlying sand-bar is washed away, the new-made land caves into the river, and the island disappears."

2. *Delta formations.*—The larger part of the detritus of a river is carried to the ocean (or lake) into which it empties, and it goes to form about the mouth of the stream more or less extensive flats. Such flats, when large and intersected by a network of water-channels, are called *deltas;* they reach a large size only where the tides are quite small or are altogether wanting. They are formed from the conjoined action of the river and the ocean, and are sometimes

called *fluvio-marine* formations. Great streams, like the Amazon, carry their muddy waters hundreds of miles into the ocean; but far the greater part of the detritus, even in the case of the largest rivers, is beaten back by the waves on soundings and by the shore-currents, and either falls over the bottom or is thrown upon the coast near by. In floods, the river-water of the Mississippi is distinguishable in the Gulf at the distance of only twenty or twenty-

Fig. 942.

Delta of the Mississippi.

five miles from the bar; in low water, at the distance of five or ten miles. (Humphreys & Abbot.)

The eastern North American coast, from Texas to Florida, and

from Florida to New Jersey, is nearly a continuous range of fluvio-marine formations.

Only a single example—that of the Mississippi delta—need here be referred to. The preceding map (fig. 942) presents its general features. It commences below the mouth of Red River, where the Atchafalaya "bayou" begins,—the first of the many side-channels that open through the great flats to the Gulf. The whole area is about 12,300 square miles, and about one-third is a sea-marsh, only two-thirds lying above the level of the Gulf.

On page 643 the amount of detritus is mentioned which the river annually furnishes towards the extension of the delta.

According to Humphreys & Abbot, the outer crest of the bar of the Southwest Pass (the principal one) of the Mississippi advances into the Gulf 338 feet, over a width of 11,500 feet, annually; and the erosive power is only about one-tenth of its depositing power. The depth of the Gulf where the bar is now formed being 100 feet, the profile and other dimensions of the river, in connection with the above-mentioned rate of deposit, give for the difference between the cubical contents of yearly deposit and erosion 255,000,000 cubic feet, or a mass one mile square and nine feet thick: this, therefore, is the volume of earthy matter pushed into the Gulf each year at the Southwest Pass. The quantities of earthy matter pushed along by the several passes being in proportion to their volumes of discharge, the whole amount thus carried yearly to the Gulf is 750,000,000 cubic feet, or a mass one mile square and twenty-seven feet thick. As the cubical contents of the whole mass of the bar of the Southwest Pass are equal to a solid one mile square and 490 feet thick, it would require fifty-five years to form the bar as it now exists, or, in other words, to establish the equilibrium between the advancing rates of erosion and deposit.

The deltas of the Nile, Ganges, Amazon, and other large streams are equally interesting subjects of study. But it is not necessary to enter into details respecting them in this place, as they illustrate no new principles.

As the forms and stratification of delta deposits depend partly upon wave-action, this subject comes up again under the head of *The Ocean*.

B. SUBTERRANEAN WATERS.

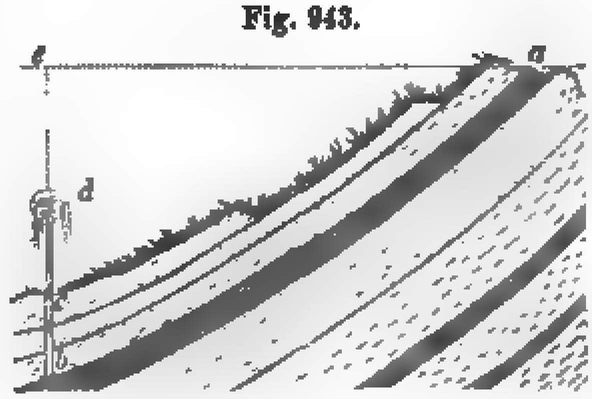
It is an obvious fact that a considerable part of the water which reaches the earth's surface descends into the soil and becomes in a sense subterranean. But there are also subterranean streams, which have their rise in hills and mountains, and are fed, like the surface-rivers, by the rains and snows, and especially those that fall about elevated regions. These waters become under-ground streams by following the dip of tilted strata. The layers of sandstones and limestones never fit together so closely but that waters may find their way between them. The subterranean streams usually flow over limestone or argillaceous strata, and not on porous sandstones.

All wells and springs are tappings of these subterranean waters. The large size of some of these under-ground rivers is proved by direct observation in caverns, where they have the variety of cascades and quiet waters which characterizes the streams of the surface. The Mammoth Cave of Kentucky, and the Adelsberg, twenty-two miles northeast of Trieste, are examples. And, again, sometimes, as in the Jura Mountains of Switzerland, they come out of the hills with sufficient force and volume to turn the wheel of a large mill.

The outward flow of the under-ground waters of a continent prevents the in-flow of the salt water on sea-shores. Springs are common on shores; occasionally their waters rise in large volume in a harbor, or out at sea some miles distant from a coast.

If subterranean streams have their rise in elevated regions, their inferior portions beneath the plains of a country must be under great hydrostatic pressure; and this should appear, whenever a boring is made to the waters, by their rising above the surface in a jet. Borings of this kind have been made in many parts of Europe and America with this effect. They were first attempted in France, and are called Artesian wells, from the district of Artois, in France, where they were early used. In fig. 943, let *a b* represent an argillaceous stratum on which the water descends, and *b c* the boring; *b c d* is the jet of water. The rise of the jet falls far short of the height of the source, because of the great amount of friction along the irregular rocky bed of the stream, and also the resistance of the air.

Fig. 943.



Section illustrating the origin of Artesian wells.

It is possible that in some cases subterranean waters may be under pressure from a stratum of gas over them, which is sufficient to send them to the surface without other aid.

The Artesian well of Grenelle, near the Hotel des Invalides, in Paris, is 2000 feet deep. At 1800 feet, water was struck, and it darted out to a height above the surface of 112 feet and at the rate of nearly one million of gallons a day. The pressure indicated by the jet was equal to that of a column of water 2612 feet high, or 1160 pounds to the square inch.

Another well, in Westphalia in Germany, is 2385 feet deep.

An Artesian boring at St. Louis has been carried to a depth of 2200 feet; but the water obtained is not pure. One at Louisville, Kentucky, 2086 feet deep,

supplies an abundance of water, though a little brackish. Several have been made in New York City connected with manufactories. In California they have been resorted to successfully for agricultural purposes.

Borings are often successful in alluvial regions fifty or one hundred miles from any high land. A second boring in the same region sometimes seriously lessens the amount of water afforded by the first, by giving the same subterranean stream a new place of exit. The layer from which the boring and jet rise may be gradually worn through by the flow, and the water, or part of it, become lost by being thus let off to a lower level.

The mechanical effects of subterranean waters are—(1) Erosion and the consequent undermining of strata; (2) Land-slides.

1. *Erosion.*—Running water will wear rocks under ground as well as above, and may excavate a channel in the same way. Caverns are made partly by erosion and partly by the dissolving action of water. A common effect of such excavations is the production of subsidences of the soil and overlying rocks, and the formation of *sink-holes.* Small shakings of the earth may be a consequence of the fractures of undermined strata.

2. *Land-slides.*—Land-slides are of three kinds:—

(1.) The mass of earth on a side-hill, having over its surface, it may be, a growth of forest-trees, and, below, beds of gravel and stones, may become so weighted with the waters of a heavy rain, and so loosened below by the same means, as to slide down the slope by gravity.

A slide of this kind occurred during a dark, stormy night in August, 1826, in the White Mountains, back of the Willey House. It carried rocks, earth, and trees from the heights to the valley, and left a deluge of stones over the country. The frightened Willey family fled from the house, and were destroyed: the house remains, as on an island in the rocky stream.

(2.) A clayey layer overlaid by other horizontal strata sometimes becomes so softened by water from springs or rains that the superincumbent mass by its weight alone presses it out laterally, provided its escape is possible, and, sinking down, takes its place.

Near Tivoli, on the Hudson River, a subsidence of this kind took place in April, 1862. The land sunk down perpendicularly, leaving a straight wall around the sunken area sixty or eighty feet in height. An equal area of clay was forced out laterally underneath the shore of the river, forming a point about an eighth of a mile in circuit, projecting into the cove. Part of the surface remained as level as before, with the trees all standing. Three days afterwards, the slide extended, partially breaking up the surface of the region which had previously subsided, and making it appear as if an earthquake had passed. The whole area measured three or four acres.

(3.) When the rocks are tilted and form the slope of a mountain, the softening of a clayey or other layer underneath, in the manner

just explained, may lead to a slide of the superincumbent beds down the declivity.

In 1806, a destructive slide of this kind took place on the Rossberg, near Goldau, in Switzerland, which covered a region several square miles in area with masses of conglomerate, and overwhelmed a number of villages. The thick outer stratum of the mountain moved bodily downward, and finally broke up and covered the country with ruins, while other portions were buried in the half-liquid clay that had underlaid it and was the cause of the catastrophe.

Similar subsidences of soil have taken place near Nice, on the Mediterranean. On one occasion, the village of Roccabruna, with its castle, sunk, or rather slid down, without disturbing or destroying the buildings upon the surface.

Besides (1) the transfer of rocks and earth, land-slides also cause (2) a scratching or planing of slopes by the moving strata and stones; (3) the burial of animal and vegetable life; (4) the folding or crumpling of the clayey layer subjected to the pressure, where the effect does not go so far as to produce its extrusion and destruction. Such crumpled or folded beds of clay are not very uncommon in alluvial regions (fig. 977).

2. THE OCEAN.

1. OCEANIC FORCES.

The ocean exerts mechanical force by means of its—

1. General system of currents.
2. Tidal waves and currents.
3. Wind-waves and currents.
4. Earthquake-waves.

The *ratio between the velocity of salt water and its force* is the same as for fresh water (p. 635); but in the application of the ratio there is a difference arising from the greater density of the former,—its specific gravity being *one-thirty-fifth* to *one-fortieth* more than that of fresh water. Having determined the size of block that any given velocity would be sufficient to transport, the size for other velocities may be deduced by means of the ratio referred to.

The *specific gravity* of sea-water varies for different parts of the ocean. For the waters of the southern ocean, it is 1.02919; the northern, 1.02757; equator, 1.02777; Mediterranean Sea, 1.0293; Black Sea, 1.01418 (Marcet). In most seas receiving large rivers, and in bays, the density is least. The specific gravity of the water of East River, off New York City, at high tide, is 1.02038 (Beck).

1. General system of currents.

The system of oceanic currents is briefly explained on page 39. It is part of the organic structure of the globe, irrespective of its

age or condition; for, whatever the temperature of the poles, there must always have been a *warmer* tropics under the path of the sun.

The prominent characteristics of these currents bearing on their mechanical effects in geological history are the following:—

1. *The rate of movement is slow.*—The maximum velocity of the Gulf Stream is five miles an hour, and the average less than one mile and a half.

The Gulf Stream is most rapid off Florida, where the hourly rate is three to five miles; off Sandy Hook, it is one mile and a half. The rate of flow of the polar current is less than one mile an hour. Kane, while shut up in the Arctic, was carried south by the current, some days, about half a mile an hour. The great oceanic current of the eastern South Pacific varies from three miles an hour to a fraction of a mile; and across the middle of the ocean it is barely appreciable. The current in the Indian Ocean, where most rapid, has the hourly rate of two miles and a quarter.

In past geological ages the rapidity of these great oceanic currents must have been less than now, if there was any difference, because of the less difference of temperature then between the equator and the poles.

2. *The currents are generally remote from coasts, and are seldom appreciable where the depth is less than one hundred feet, and very feeble where less than one hundred fathoms.*—Owing to the great depth of the oceanic movement, the waters are diverted along the borders of the oceans by the deep-sea slopes of the continents. In the case of the Gulf Stream, these approach the coast at Cape Florida, and somewhat nearly at Cape Hatteras; but off New Jersey they are eighty to one hundred miles distant; and here runs the western limit of the stream.

The polar or Labrador current, which is mostly a sub-current, comes to the surface along the same slope, west of the limit of the Gulf Stream, and is slightly apparent on the coast plateau, but rather by its temperature than by the movement of the waters. The more western position of the limit of the polar current is explained on page 41. The fact that it has not more rapid movement on the great shore-plateau is evidence that it belongs to the deep water. This appears further in the current's underlying the Gulf Stream, and its banding the stream with colder and warmer waters, as shown by the Coast Survey under Professor Bache. The observations of the survey have proved that there are mountain-ridges apparently parallel with the Appalachians along the course of the stream in its more southern part, and that above these ridges the surface-waters are cooler, owing to the lifting

upward of the polar current by the submarine elevations. The fact that the cold waters produce a temperature of 35° F. at a depth of six hundred fathoms off Havana (as stated by Bache) is proof of the great magnitude of the polar current.

Where the current flows close along a coast or submarine bank, or by an oceanic island, it may produce some effects.

3. *As the position of the main flow of the currents is determined partly by the trend of the continents, their courses may have been different in former time from what they are now, provided the continents, or large portions of them, were sufficiently submerged.*—Small subsidences would not suffice to produce a diversion from their present courses, for the reason just given. Even the barrier of Darien might be removed by submergence to a depth of five hundred feet, and probably one thousand, without giving passage to much, if any, of the Gulf Stream. If, however, the straits were so deeply sunk that the Gulf Stream passed freely into the Pacific (the West India islands being also in the depths of the ocean, as would be necessary for the result), a great change would thereby be produced in the temperature both of the Atlantic and Pacific,—a loss of heat to the former and a gain to the latter (see Physiographic Chart). But no facts yet observed prove this supposition to have been a realized fact since the opening of the Silurian age.

Besides the general system of currents which has been considered, there are currents between the ocean and some confined seas opening into it, which are due to the evaporation going on over the surface of those seas. The consequent diminution of water causes a flow from the ocean to supply the loss. This happens at the Straits of Gibraltar opening into the Mediterranean. In many seas of this kind the accessions from rivers more than supply the amount removed by evaporation, and these produce an out-current at the entrance.

2. Tidal waves and currents.

1. *Rise and fall of tides.*—The simplest of tidal actions is the periodical rising of the waters on a coast. The in-flow acts like a dam in setting back the waters of springs and rivers. It floods large areas on flat coasts, which are thereby made salt marshes.

The height of the tide is less in mid-ocean than along the continents, and is greatly augmented where the two coast-lines converge, as on entering a bay, and especially where there is free entrance to a channel from two directions. In the middle Atlantic, at St. Helena, it is two or three feet; at the Azores, three feet; on the Atlantic coast of the United States, from five to twelve feet; but in the Bay of Fundy, fifty to seventy feet. In the cen-

tral Pacific, the height is two to four feet; and at Tahiti, high tide occurs always at noon.

2. *Translation character of the tidal waves.*—The tidal waves which succeed one another around the globe become appreciably translation or propelling waves on soundings; and directly upon a coast, especially along its deeper bays or inlets, they constitute a force of great energy. The borders of all the continents and islands feel this power and exhibit its effects.

3. *In-flowing tidal currents.*—The in-coming tide generally strikes one part of a coast before another, owing to its trend with reference to the wave, and, consequently, has a progressing movement along it. This is very marked on the shores of southern New England.

The tidal current becomes one of great strength where there are narrow channels to receive and discharge the waters.

The movement may have the violence of a river-torrent when the entrance to bays is of a kind to temporarily dam up the waters until the far-advanced tide has so accumulated them that they overcome the resistance and pass on in a body.

In the Bay of Fundy, the waters of the in-coming tide are raised high above their natural elevation, so that as they advance they seem to be pouring down a slope, making a turbid waterfall of majestic extent and power, without foam. The tide at Bristol, England, has a height of forty feet.

In some cases the whole tide moves in all at once, in a few great waves. This happens especially at the mouths of rivers where there is obstruction from sand-bars, and other favoring circumstances about the entrance. The phenomenon is called an *eagre* or *bore.* The flow of the tides at the Bay of Fundy has something of the character of an eagre. But the most perfect examples are afforded at the mouths of the rivers Amazon, Hoogly (one of the mouths of the Ganges), and Tsien-tang in China. In the case of the last-mentioned river the wave plunges on like an advancing cataract, four or five miles in breadth and thirty feet high, and thus passes up the stream, to a distance of eighty miles, at a rate of twenty-five miles an hour. The change from ebb to flood tide is almost instantaneous. Among the Chusan Islands, just south of the bay, the tidal currents run through the funnel-shaped firth with a velocity of sixteen miles an hour. (Macgowan.)

In the eagre of the Amazon, the whole tide passes up the stream in five or six waves, following one another in rapid succession, and each twelve to fifteen feet high.

4. *Out-flowing currents.*—The ebbing tide causes an out-flowing

current, which is directly the counterpart of the in-flowing current. It is more quiet than the latter in its movement, although often a rapid and powerful current, because more contracted in width,—and especially so in bays, where the waters of a river add to the volume of the ebb. Wind-waves may increase greatly the force of the in-coming tide, but not so with the out-flowing, since waves always act shoreward.

The piling of the tidal waters to an unusual height in converging bays, raising them far above their level outside, is another powerful cause of out-flowing currents. The flow is along the bottom; and in a case like that of the Bay of Fundy it must have great power.

3. Ordinary wind-waves and currents.

1. *Waves.*—The winds are almost an incessant wave-making power. Even in the calmest weather there is some breaking of wavelets against the rocky headlands or the exposed beach; and with ordinary breezes the beaches and rocks are ever under the beating surge, night and day, from year to year. Most seas, moreover, have their storms, and in some, as those about Cape Horn, gales prevail at all seasons. The breakers on the shores of the Pacific are especially heavy, on account of its extent and depth.

Through a large part of the ocean the winds are constant in direction, either for the year or half-year.

Stevenson, in his experiments at Skerryvore (west of Scotland), found the average force of the waves for the five summer months to be 611 pounds per square foot, and for the six winter months, 2086 pounds. He mentions that the Bell Rock Lighthouse, 112 feet high, is sometimes buried in spray from ground-swells when there is no wind, and that on November 20, 1827, the spray was thrown to a height of 117 feet,—equivalent to a pressure of nearly three tons per square foot.

2. *Surface-currents.*—Winds also cause *currents*. The prevailing winds of an ocean, like the trades (p. 44), cause a parallel movement in the surface-waters; and when the direction is reversed for half the year, as in the western half of the tropical Pacific, the current is changed accordingly. These currents become marked along shores, and especially through open channels. Prolonged storms often produce their own currents, even in mid-ocean, and more strikingly still among the bays and inlets of a coast.

These currents made by the winds are inferior in power to the tidal currents among the inlets and islands of a continental coast: but about oceanic islands they are often of greater strength.

3. *Under-currents.*—The forcing of waters into bays, whether by regular winds or storms, causes a strong under-current outward, like that from the tides. This is especially marked when the entrance of the bay is broad, so as to allow of an in-flow over a wide area, while the deep-water channel is narrow. In some cases, ships lying at anchor feel this under-current so strongly as to "tail out" the harbor in the face of a gale which is blowing in.

In the ordinary breaking of waves on a beach or in rocky coves, there is an under-current (or under-tow) flowing outward along the bottom. The wave advances and makes its plunge, and then its waters flow back beneath those of the next wave, which is already hastening on towards the beach.

4. Earthquake-waves.

In an earthquake, the movement of the earth may be either (1) a simple vibration of a part of the earth's crust; or (2) a vibration with actual elevation or subsidence. In each case, the ocean-waves which the earthquake, if submarine, may produce, have an actual forward impulse, and are, therefore, *forced* or *translation waves*. They have great power; and, as there is no narrow limit to the amount of elevation which may attend an earthquake, such a wave may be of enormous height. An earthquake at Concepcion, Chili, set in motion a wave that traversed the ocean to the Society and Navigator Islands, 3000 and 4000 miles distant, and to the Hawaiian Islands, 6000 miles; and on Hawaii it swept up the coast, temporarily deluging the village of Hilo.

2. EFFECTS OF OCEANIC FORCES.

The effects of oceanic forces are here treated under the heads of—(1) Erosion; (2) Transportation; (3) Distribution of Material, or Marine and Fluvio-marine formations.

1. Erosion.

1. *Transportation by currents.*—The great oceanic currents are in general too feeble to transport material coarser than fine sand, and too remote from coasts to receive any detritus, except from the very large rivers, like the Amazon. Still, the Labrador current, with its westward tendency (p. 41), acting against the submerged border of the continent, must have always produced some southwestward transporting effects. The existence of the slope as the true out-

line of the oceanic basin (p. 12) with more probability fixes the course of the currents.

The *tidal flow* and *upper wind-currents* may produce results similar to those of fresh-water streams of equal velocity.

The *ebbing tide* and the *under-currents* act on the bottoms of inlets and harbors, and especially their channels, and are an important means of keeping them open to the ocean and of modelling their forms.

2. *Erosion by waves.*—The waves bring to bear the violence of a cataract upon whatever is within their reach,—a cataract that girts all the continents and oceanic islands. In stormy seas, they have the force of a Niagara, but with far greater effects; for Niagara falls into a watery abyss, while in the case of the waves the rocks are made bare anew for each successive plunge. It is not surprising, therefore, that in regions like Cape Horn or the coast of Scotland, where storms are common and the bordering seas deep, the cliffs should undergo constant degradation and be fronted by lofty castellated and needle-shaped rocks. The action of the ordinary breakers is sufficient to wear the rocky shores, reduce stones to gravel and sand, and grind the sands of beaches to a finer powder.

The cliffs of Norfolk and Suffolk, England, afford an example that has been long under observation, as the country is one of houses and cultivated fields. Lyell states that when the present inn at Sherringham was built, in 1805, it was fifty yards from the sea, and it was computed that it would require seventy years for the sea to reach the spot,—the mean loss of land having been calculated, from former experience, to be somewhat less than one yard annually. But it was not considered that the slope of the ground was *from* the sea. Between the years 1824 and 1829, seventeen yards were swept away, bringing the waters to the foot of the garden; and in 1829 there was depth enough for a frigate (twenty feet) at a spot where a cliff of fifty feet stood forty-eight years before. Farther to the south, the ancient villages of Shipden, Wimpwell, and Eccles have disappeared. This encroachment of the sea has been going on from time immemorial. Many examples might be cited from the American coast, but none as remarkable have yet been described.

These effects of the sea on coasts depend on (1) the height of the tides; (2) strength and direction of tidal currents; (3) direction of the prevalent winds and storms; (4) force of the waves; (5) nature of the rock of the shores; (6) outline of the coast.

Soft sandstones in horizontal layers, and beds of gravel or earth, are easily removed. But granite, gneiss, quartz rock, and trap or basalt, undergo usually but slow wear. Projecting headlands, which stand out so that the sea can batter them from opposite directions, are especially exposed to degradation, and particularly those on windward coasts.

3. *The wearing action of waves on a coast is mainly confined to a height*

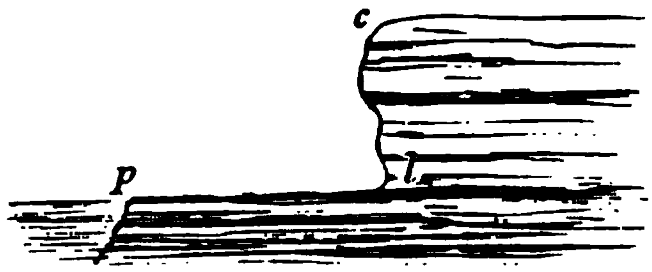
between high and low tides.—Since a wave is a body of water rising above the general surface, and when thus elevated makes its plunge on the shore, it follows that the upper line of wearing action may be considerably above *high-tide* level.

Again, the lower limit of erosion is above *low-tide* level, for the waves have their least force at low tide, and their greatest during the progressing flood; and when the waves are in full force, the rocks below are already protected by the waters up to a level above low-tide mark. There is, therefore, a level of greatest wear, which is a little above half tide, and another of no wear, which is just above low tide.

This feature of wave-action, and the reality of a line of no wear above the level of low tide, are well illustrated by facts on the coasts of Australia and New Zealand.

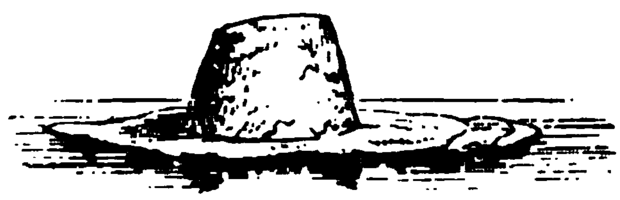
In figure 944 (representing in profile a cliff on the coast of New South Wales near Port Jackson), the horizontal strata of the foot of the cliff extend out in a platform a hundred yards beyond the

Fig. 944.



Cliff, New South Wales.

Fig. 945.



"The Old Hat," New Zealand.

cliff. The tide rises on the platform, and the waves, unable to reach its rocks to tear them up, drive on to batter the lower part of the cliff. At the Bay of Islands, New Zealand, the rocks have no horizontal stratification, and, still, there is the same sea-shore platform; and an island in the bay (fig. 945) is called "The Old Hat." The *sea-shore platform of coral islands* has the same origin. The *stability of sand-flats* in the face of the sea is owing to this cause.

In seas of high tides and frequent storms, the platform is narrow or wanting, owing to the tearing action of the heavy waves.

2. Transportation.

1. *Transportation by currents.*—The great oceanic currents are too feeble to transport any material coarser than fine sand, and too remote from coasts to receive detritus of any kind, except sparingly from the very largest of rivers, like the Amazon. Whatever sinks in the main course of the Gulf Stream is carried some distance southward again by the polar current beneath it.

Sea-weeds are borne on by the Gulf Stream in great quantities, and thrown off on the inner side of the current into the great area of still water about the centre of the North Atlantic, called, from the common name of the plant (a species of Fucus), the *Sargasso Sea*. With the sea-weeds, there is a profusion of small life,—fishes, crabs, shrimps, Bryozoans, etc.

Pourtales, in microscopic examinations of soundings from beneath the Gulf Stream, found an abundance of the shells of Rhizopods, and almost no proper detritus. Bailey suggested that these minute cellular shells were drifted to their place by the stream; but Pourtales concludes, from his observations, that they live at the depths in which they are found.

In polar seas, where there are glaciers and icebergs, large quantities of gravel, earth, and boulders are often floated off on the bergs. From the Arctic they are borne south by the polar current to the Banks of Newfoundland; there the icebergs encounter the edge of the Gulf Stream, and melt, dropping their freight over the bottom.

Tidal and *wind currents* have the same powers of transportation as rivers of equal velocity.

2. *Transportation by waves.*—As follows from the force of waves against shores, stated on p. 654, they have great transporting power; but their action is confined to narrow limits of depth, and is exerted mainly when the plunging waters strike and dash upon a sandy or rocky coast. Large rocks often have their buoyancy increased by the sea-weeds attached to them.

Stevenson reports that a block of gneiss of 504 cubic feet (about forty-two tons) lying on a beach (in Scotland) was moved five feet by the waves during one storm, and was then so wedged in that its farther progress was prevented. The in-coming wave, as it struck it, gave it a shove, and, pushing on, buried it from sight, making a perpendicular rise of thirty-nine or forty feet; and in the back run the mass was again uplifted with a jerk.

Marine animals, or their relics, and sea-weeds, are thrown abundantly on coasts by the waves; and, in some regions, whales that venture too near the land are carried up and left floundering on the sand. This happens not unfrequently about the Chusan Islands in the China Seas, where the tidal currents have great force (p. 653).

In the case of the heaviest waves, and especially earthquake-waves, the waters first retreat to an unwonted distance, and then advance in their might, striking deep, and tearing up strata that at other times are under the protection of the waters.

In the wave-movement on soundings, and not close in-shore, the propulsion of each wave is very small; and its power of accomplish-

ing great transporting effects lies in its incessant action. The waves thus beat back the detritus thrown out by rivers, and cause them to be deposited mainly over the bottom in the shallower waters, and against the shores, and so prevent their being lost to the land by sinking in the depths of the ocean.

In the passage of the great wave of the eagre on the Tsien-tang (p. 653), the boats floating in the middle of the stream rise and fall on the tumultuous waters, but are carried only a very short distance forward. Yet, along the sides of the river, the wave tears away the banks, and in places sends a deluging flood over the shores, a true tidal current, which devastates the country.

It follows, from the facts stated, that no continent can contribute to the detrital accumulations of another continent except through the aid of icebergs. Had there formerly existed a continent in the midst of the present North Atlantic, America would have received from it little or no rock-material. The tides and waves, and tidal and wave currents, all work shoreward.

3. Distribution of material, and the formation of marine and fluvio-marine deposits.

1. *Oceanic Formations.*

The deposits of oceanic currents consist only of fine detritus: no conglomerates or coarse sandstones can, therefore, be made from them. The Gulf Stream has little power in making such deposits, as it carries along scarcely any detritus. The bottom of the Atlantic between Ireland and Newfoundland consists almost solely of the shells of microscopic organisms (p. 612).

By means of *icebergs*, the currents of the ocean may distribute widely the coarsest of rock-material; but nearly all the icebergs of the North Atlantic drop their loads of gravel and stone in the vicinity of the American continent, and not in mid-ocean. The *deposits made by icebergs* consist of gravel, sand, and stones of all sizes, up to many tons in weight, promiscuously mingled, without stratification. They are thus unlike all the rock-formations over the continent preceding the period of the Post-tertiary.

Mr. Babbage has shown that, taking four kinds of detritus, of such a size, shape, and density that they would sink—the *first* kind 10 feet an hour, the *second* 8, the *third* 6, the *fourth* 4, then if a stream containing this detritus were 100 feet deep at mouth, and entered a sea having a uniform depth of 1000 feet, and a rate of motion of two miles an hour, the first kind would be carried 180 miles before

the first portions would reach bottom, and would be distributed along for 20 miles; the corresponding numbers for the others would be—(2) 225 and 25; (3) 360 and 40; (4) 450 and 50. Thus, four kinds of deposits would be formed from the same stream, at different distances from its mouth.

2. *Formations on Soundings and along Coasts.*

1. *Origin of the material.*—The material of sea-shore formations is derived from two sources: (1) the detritus of rivers; (2) the wear of coasts.

All the rivers entering an ocean bring in more or less detritus, especially during freshets. The quantity from the Mississippi is stated on page 644. The amount thus contributed to the ocean depends on the geographical extent of the river-systems bordering it, and the annual amount of rain, snow, etc. In both these respects, North and South America exceed the other continents; and the ocean which receives the detritus is the Atlantic.

2. *Distribution and accumulation.*—The distribution and accumulation of the material may take place (1) from the action of waves alone; (2) from waves, and tidal or wind currents; (3) from the waves, the shore-currents, and the currents of rivers.

(1.) The accumulations made by *waves* are either in the form of beaches or off-shore deposits of detritus. As the plunge of the wave is analogous to that of a torrent, its waters, while grinding the material upon which they act, wash out the finer portion, and carry it away by means of the under-tow. The beach consequently consists of more or less coarse material, according to the strength of the waves: it may be sand, pebbles, or even large stones, if the rocks of the coast are of a nature to afford them. In sheltered bays, where the waves are small, trituration is gentle, and the material of the beach may be a fine mud or silt.

The height of a beach depends on the height of the tides and the strength of the waves. The sands thrown beyond the farthest reach of the waves are often accumulated into higher ridges, and make the wind-drifts and dunes described on page 629.

(2.) The *tidal and wind currents* give direction to the material taken up by the waters. This material may be the sands, stones, etc. of a beach, or the finer material from the bottom, or the mud stirred up from greater depths, down even to 100 feet, by the heavy waves of storms. The currents, their general course being otherwise determined, flow where they find the freest and deepest passage, and drop their detritus wherever there is a diminution of velocity. This precipitation takes place in the waters thrown off either side of the

current, and especially the shoreward side, towards which the waves set the floating material; also where capes make a lateral eddy, and where any obstruction tends to retard the waters. A vessel sunk in the passage may divert the waters a little to one side, where they may have an easier flow, and become itself the basis of an accumulating sand-bank.

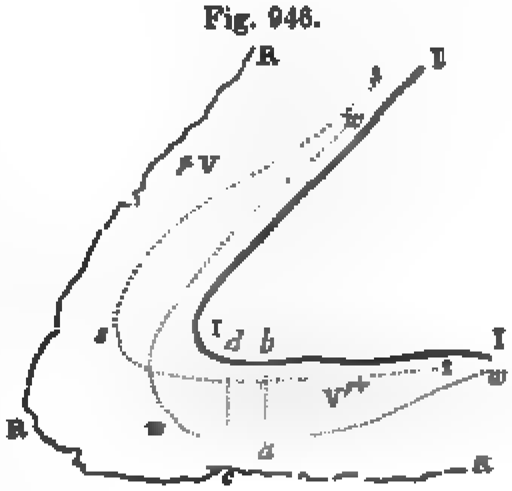
The increase and shaping of a sand-spit depend usually on the action of the in-flowing tidal current and waves on the outer side, and that of the out-flowing on the inner, the latter being the deeper and often the more effectual.

This point is well illustrated by Captain Davis in his excellent paper on the geological effects of tidal action. He mentions the cases of long points thus made on the eastern extremity of Nantucket, where the current on the outside of the island sets from the west to the east, and from the south to the north. Vessels wrecked on the south side of the island have been carried by it, in piecemeal, eastward, and then northward to the beach north of Sankaty Head. The coal of a Philadelphia vessel, lost at the west end of the island, was carried around by the same route to the northern extremity.

Where the wind-current changes semi-annually, the accumulations made by the current when flowing in one direction are sometimes transferred to another side of an island or point during the next half-year.

A. Hague states, in a recent article, that at Baker Island (of coral), in the Pacific (0° 15′ N., 176° 22′ W.), this fact is well exhibited. In fig. 946, I I I is the southwest point of the island, and R R R, the outline of the coral-reef platform, mostly a little above low-tide level; its width, *c d*, 100 yards. In the summer season, when the wind is from the southeast, the beach has the outline *s, s, s*; during the winter months, when the wind is northeast, the material is transferred around the point, and has the position *w, w, w*, having a width at *a b* of 200 feet. A vessel wrecked in summer, and stranded at V, was transferred to V′ in the course of the month of November.

Fig. 946.



(3.) The combination of *wave-action and marine currents with the currents of rivers* produces results analogous to those proceeding from marine currents and waves alone, but with greater complication, and, in the present age, of far greater extent, because rivers add so vastly to the material of deposits by their detritus.

The flow of rivers and the movements of the ocean are, in general,

in direct opposition. The in-flowing tide sets back the rivers, quiets the waters, and floods the adjoining tidal flats; and consequently a deposition of detritus takes place over the flats, and the bed of the stream. The turn of the tide sets the river again in full movement, and it takes up the detritus deposited over its bed (but only little of what fell over the flats) and bears it to the ocean. Here the current loses much of its velocity in the face of the waves and with the spreading of the waters, and hence a deposition of detritus goes on: this continues until the next tidal flow dams up the fresh-water stream anew. Between the ocean and the river there is a region of comparative equilibrium in the two movements, and there the accumulations of sand or detritus take place, forming sand-bars.

Fig. 947.

Fluvio-marine formation along the coast of North Carolina.

Humphreys and Abbot observe, in speaking of the Mississippi delta, that as the river-water rises above the salt water, from its low density, there is a dead angle between the two. The current out the Passes pushes sand and earth before it, until, reaching, it begins to ascend upon, the salt water of the Gulf, and here this material "is left upon the bottom in the dead angle of salt water. A deposit is thus formed, whose surface is along or near the line upon which the fresh water rises on the salt water as it enters the Gulf; and this action produces the bar."

The distance off the mouth of a river of these sand bars or barriers will depend on the size and strength of the rivers on one side, and the height and force of the tides on the other. Small streams are often blocked up entirely by a sand-bar across their mouths, and the waters reach the ocean only by percolation through the beach. Large streams make distant sand reefs and barriers even in the face of the ocean. The North American coast from Long Island to Florida is fronted by ranges of barrier reefs shutting in extended sounds or narrow lagoons.

The accompanying map of Pamlico Sound and the region about Cape Hatteras (fig. 947) illustrates this feature of the continent.

The numerous rivers of this well-watered coast carry great quantities of detritus to the ocean,—part of which is borne out to sea to raise the great submarine plateau of the coast, and another part is added to the barrier and to the banks and flats of the Sound. The contraction of the Sound, which is going on by the additions to the flats and over its bottom, gradually prolongs the channel of the river towards the ocean. This gives greater force to the river-current, and it acts in conjunction with the strong ebb tide against the inner side of the barrier, in slowly wearing it away. At the same time, the outflowing stream and tidal current carry a greater quantity of detritus into the ocean, contributing sand to the beach and finer detritus to the plateau, the nature of wave-action on a beach being such as to leave only the sand or coarser material. Thus, by a slow process, the mainland gains in breadth, and the river in length, and the barrier moves gradually seaward. In other cases, the lagoons inside of the barrier become filled, and a continuous marsh, and ultimately dry land, is made out to the barrier. All the low lands along the eastern coast of the continent, and that bordering on the Gulf of Mexico, in most parts many scores of miles in breadth, have been made in the manner here pointed out.

When the tides are very small, or fail altogether, the rivers may reach the sea by many mouths without the formation of barriers, or, in other words, may form true deltas. The height of the tide of the Mexican Gulf along the north shore is but twelve to fifteen inches; and, consequently, while most of the streams, before even this small tide, have their bars and barriers, the great Mississippi sends its many arms far out into the Gulf, prolonging its channels in the face of winds, waves, and tide (fig. 942, p. 646). Incipient sand-bars at times form; but these serve only to divide one of the great channels, and make a new branch.

The course of the out-flowing currents during ebb tide, in conjunction and alternation with the in-flowing tidal current and waves, determines the position of the channels and sand-bars, and causes the prolongation of *hooks* off prominent capes. In some cases, wind-currents are concerned in the action. The general process is the same as when only the currents of the ebb and flow are concerned; but the ebb tide has far greater effect from the added volume, velocity, and detrital material of the river. The out-flowing currents are deep and strong, sweeping out the channels of bays and lagoons, and moulding the sand bars and spits; while the in-flowing move in a more diffused manner, and with much less rapidity and

effect. Prof. Bache has thus explained the increase of Sandy Hook (the southern cape at the entrance of New York Bay). His observations prove that the current during ebb tide is most effectual in prolonging and shaping the Hook, though the in-flowing tide contributes to the result, and the waves aid in giving the hook-like form by bending in the extremity. The Hook has been elongated at the rate of "one-sixteenth of a mile in twelve years," since the time when the first precise observations were made.

3. *Structure of the formations.*

Beach-formations are irregularly stratified, the layers being much interrupted, and varying every few rods or less, as represented in fig. 61 *d*, p. 93. The layers are either of sand, gravel, pebbles, or stones. In the lower part, where washed by the tides, they often slope seaward a few degrees. Over the area of shallow waters outside, the deposits in progress consist mostly of fine detritus, either sandy or argillaceous, with rarely pebbles, except near the beach; and through the greater part argillaceous beds prevail, as shown by soundings. The beds may be uniform over very large surfaces. These regions are fifty to eighty miles wide on the eastern border of North America (fig. 664, p. 441). In the lagoons or bays, argillaceous deposits are the most extensive; but sand and pebbles may be distributed among them, especially off the mouths of streams.

As stated on page 612, the material of the bottom of the submerged plateau, above referred to, outside of a depth of 90 feet, consists at surface one-half of Rhizopod shells. Off southern New England, at depths between 300 and 550 feet, from a region southeast of Montauk Point to that southeast of Cape Henlopen, the soundings, according to Bailey, consist *chiefly* of these shells. At greater depths, beyond the limit of the plateau, Pourtales found almost a pure floor of Rhizopods. The species are deep-water species, differing thus from those of the New Jersey Cretaceous beds. Pourtales observes, in a recent letter to Professor Bache (dated May 17, 1862), that along the plateau between the mouth of the Mississippi and Key West, for two hundred and fifty miles from the mouth, the bottom consists of clay, with some sand and but few Rhizopods; but beyond this the soundings brought up either Rhizopod shells alone, or these mixed with coral sand, Nullipores, and other calcareous organisms.

As microscopic life abounds in harbors where rivers make frequent depositions of sediment, the presence of a considerable proportion of Rhizopods is consistent with an annual increase of the plateau from sedimentary depositions. (Bailey, Smithsonian Contrib. ii.; Amer. Jour. Sci. [2] xvii. 176, and xxii. 282; Pourtales, Trans. Amer. Assoc., Charleston meeting, 1850, 84; Reports Coast Survey for 1853, p. 83, and 1858, p. 248.)

Ripple-marks are often made by the waves over the finer beach-sands, where they are low and partly sheltered, and also over mud-flats. The flowing water pushes up the sand into a ridgelet, as high

as the force can make, and then plunges over the little elevation and begins another; and thus the succession is produced. The height and breadth of the intervening space will depend on the force and velocity of the flowing water, and the ease with which the sand or mud is moved. Ripple-marks may be made by the vibration of waves even at depths of 300 to 500 feet.

The rapid in-flowing tidal or other current over the sands of sand-bars, and the bottoms of bays, may produce an effect similar in general character to ripples, although on too large a scale to be recognized as such. The *oblique lamination of layers*, represented in fig. 61 *c*, p. 93, is probably a result in this way of a pushing action in waves or currents.

When a wave dies out on a beach, it sometimes leaves a tracing of its sweep on the sand, as a *wave-line;* and the returning waters flowing by any half-buried shell or stone may make rills in the sand, or *rill-marks* (fig. 63, p. 94).

Broken shells, and other marine relics in fragments, are common in beach-deposits. Below high-tide level, there may be the vertical borings of sea-worms, of certain Crustaceans (as species of the *Callianassa* family), and some Mollusks. In the off-shore shallow waters occur beds of living Mollusks, and other kinds of animals, as well as plants, varying according to the depth.

4. *Action of the oceanic waters over a submerged Continent, and during a gradual submergence or elevation.*

1. *Marine deposits.*—The most obvious effect of the slow submergence of a continent beneath the waters of the ocean would be the working-over, by the waves and marine currents, of the loose earth, gravel, and alluvium of the surface, thereby changing them into marine deposits. The depth to which this alteration would extend would, for the most part, be much less, probably, than a hundred feet. Whatever the extent, the ocean, besides exterminating living species, would obliterate most of the remains of terrestrial life in the altered deposits, and introduce its own living Mollusks and other tribes throughout the new continental seas.

2. *Features of the surface not altered by an excavation of valleys, but by a diminution of its heights and a filling of pre-existing valleys.*

It might be supposed, at first thought, that the ocean would wash through the valleys with great excavating force, and make deep gorges over the surface. The real effect will be best learned from the present action on sea-coasts; for with every foot of submergence the sea-beach would be set a little farther inland, so that the whole would successively pass through the conditions of a sea-

shore. On existing sea-shores the action in progress, instead of tending to excavate valleys, produces just the contrary effect. It is everywhere wearing off exposed headlands, and filling up bays. The salt waters, in fact, enter but a short distance the river-valleys of a coast, because they are excluded by the out-flowing stream. The bottom of the Hudson is below the sea-level for a long distance beyond the limit to which the pure ocean-water extends: the same is true of the St. Lawrence, and of many other rivers along the coast. During a progressing submergence, therefore, the ocean would have no power of excavating narrow valleys, unless they happened to be open at both ends, so as to allow the oceanic currents to sweep through.

As the submergence progressed, there would be, through wave-action, extensive degradation of the ridges and mountains over the surface, and a distribution of the detritus through the intervening depressions. In a subsequent emergence of the land, the mountains and ridges would be still further degraded, and the valleys filled by their debris. The laws of sea-coast action would again come into play, and the wear of all new headlands, and the filling of bays, continue to be the result, as long as the emergence was in progress.

3. *Effects as to the formation of marine deposits when a continent is mostly without mountain-ranges and valleys.*

If the continent were to a large extent without mountains, the broad flat surface might then lie slightly above or below tide-level at once, or nearly simultaneously, so that under a small change of level the waves could sweep across the whole area. It has been shown that the Appalachian Mountains were not raised until after the Carboniferous age, and the greater part of the Rocky Mountains not before the close of the Cretaceous period. The North American continent was, therefore, in early time, in the condition here supposed; and the older formations have a corresponding extent and character. There were continental oscillations, causing slight emergences of large areas to alternate with varying submergences, and through such changes the variations in the formations were produced, differences of depths causing transitions from arenaceous to argillaceous or to pebbly and conglomeritic accumulations; and the differences required for such changes are so small that the probability of finding the cotemporaneous fragmental deposits of Europe and America, or even of distant parts of one continent, alike arenaceous, argillaceous, or conglomeritic, is exceedingly small. The details of the history as regards North America have already been given, and need not be here repeated.

3. FREEZING AND FROZEN WATER.

Water performs part of its geological work in the act of freezing, and another part when frozen, in the condition of snow and ice.

1. WATER FREEZING.

Rending and disintegration from expansion.—As water in freezing expands on reaching 39¼° F., the freezing-process in the seams of rocks opens those seams, tears rocks asunder, and tumbles fragments and masses down precipices; or in porous strata it crumbles off the surface, and causes disintegration. Consequently, bluffs in a cold climate, like the trap hills of Connecticut and the highlands of the Hudson, have a long talus of broken stone made mainly by this means,—while in a tropical climate the precipices are generally free from fragments. This cause of degradation goes on incessantly in all icy regions where there are melting and freezing, and may have originated much of the soil and drift of the globe.

2. ICE OF RIVERS AND LAKES.

Ice forming along streams in which there are stones envelops the stones in shallow water, even to a depth of two or three feet, or more in the colder climates. Other stones and earth fall on the ice from the banks. When the floods of spring raise the stream and break up the ice, both ice, and stones, often float down stream with the current, or are drifted up the banks high above their former level, or are spread over the river-flats.

Ice sometimes forms about stones in the bottom of rivers when the rest of the water is not frozen, and is then called *anchor-ice.* In this condition, it may serve as a float to raise the stones and to transport them with the aid of the current.

The same modes of transportation are exemplified in lakes as in rivers, except that there is less current, and the stones are mostly set back up the shore. Large accumulations of stray stones far above the ordinary level of the lake are in some places thus made.

3. GLACIERS.

1. General features, formation, and movement of Glaciers.

1. *Nature of Glaciers.*—Glaciers are accumulations of ice descending by gravity along valleys from snow-covered elevations. They are ice-streams, 200 to 5000 feet deep or more, fed by the snows and

frozen mist of regions above the limits of perpetual frost. They stretch on 3000 to 6000 feet below the snow-line (limit of perpetual snow), because they are so thick masses of ice that the heat of the summer season is not sufficient to melt them. Some of them reach down between green hills and blooming banks into open cultivated valleys. The extremities of the glaciers of the Grindelwald and Chamouni valleys lie within a few hundred feet of the gardens and houses of the inhabitants. Each glacier is the source of a stream, made from the melting ice. The stream begins, high in the mountains, from the waters that descend through the crevasses to the ground beneath, and often makes a tunnel in the ice above its course; finally it gushes forth from its cavernous crystal recesses a full torrent, and hurries along over its stony bed down the valley.

2. *Glacier regions.*—The best known of glacier regions is that of the Alps. The chain west of the head-waters of the Rhone is divided into two nearly parallel ranges, a southern and a northern. The latter includes, besides minor areas, two large glacier districts, —the Mt. Blanc and the Mt. Rosa or Zermatt district; and the former, one of equal extent, though its peaks are less elevated,—that of the Bernese Oberland. There is another district of glaciers at the head-waters of the Rhone, and others farther eastward.

Glaciers occur also in the Pyrenees, the mountains of Norway, Spitzbergen, Iceland, the Caucasus, the Himalayas, the southern extremity of the Andes, in Greenland, and on Antarctic lands. One of the Spitzbergen glaciers stretches eleven miles along the coast, and projects in icy cliffs 100 to 400 feet high. The great Humboldt glacier of Greenland, north of 79° 20′, has a breadth at foot, where it enters the sea, of forty-five miles; and this is but one among many about that icy land.

3. *Many Glaciers from one Glacier district.*—The following map (fig. 948) represents the Mt. Blanc glacier region, excepting a small part at its southwestern extremity. The vale of Chamouni along the river Arve bounds it on the northwest, and the valley of the river Doire on the southeast. This mountainous area, though one vast field of snow, gives origin to numerous glaciers on its different sides, —each principal valley having its ice-stream. The series of dotted curves show the courses of the several glaciers. B is Mt. Blanc; *bs*, the Glacier des Bois, or Bois Glacier (so named from a village near the foot of the glacier); *m*, the *Mer de Glace*, an upper portion of this glacier. The river Arveiron issues from the extremity of the glacier, and, after a short course, joins the Arve near the village of Chamouni. The Géant (*g*), Talèfre (*ta*), and Lechaud (*l*) glaciers are the three largest of the upper glaciers which combine to form

Figs. 948–952.

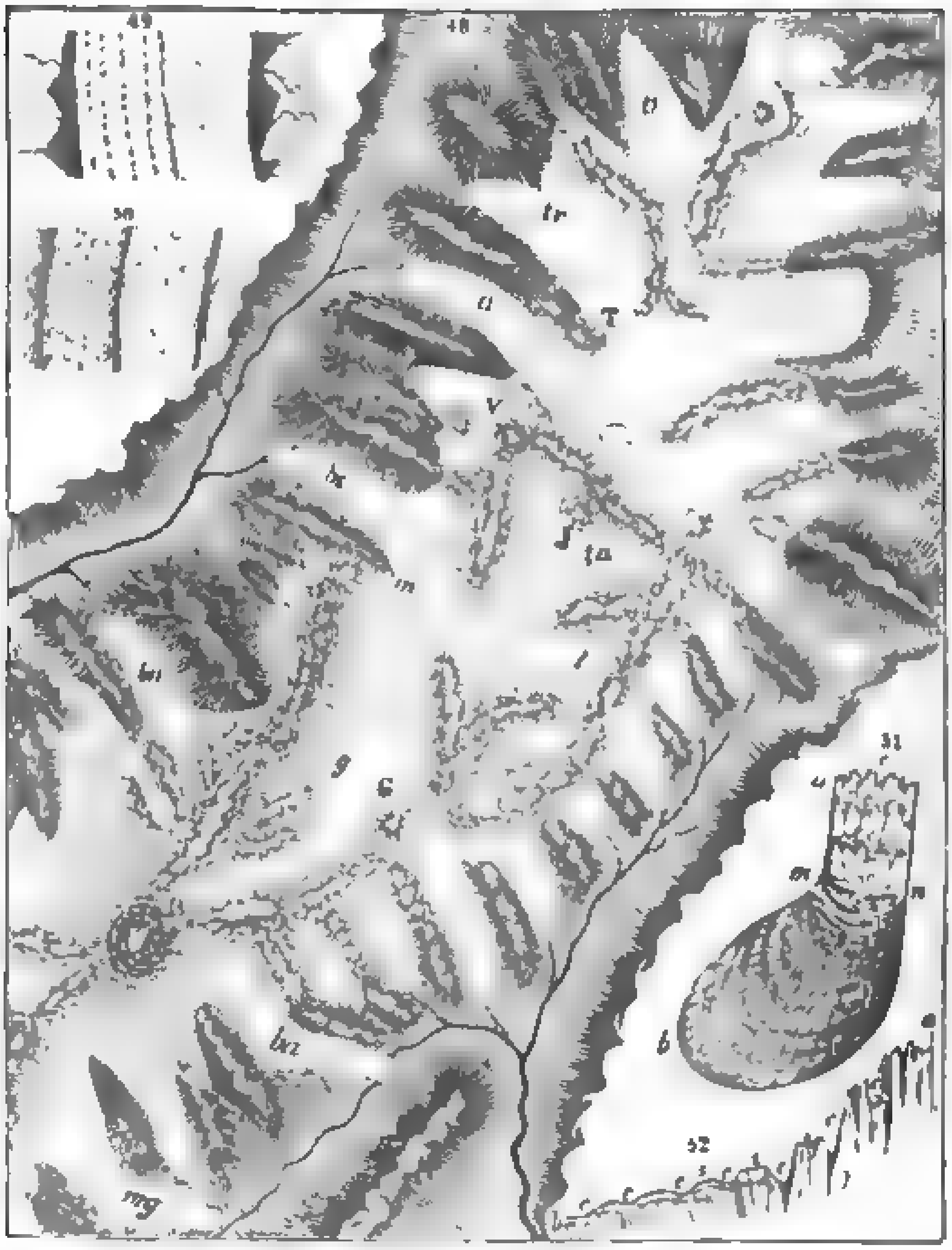


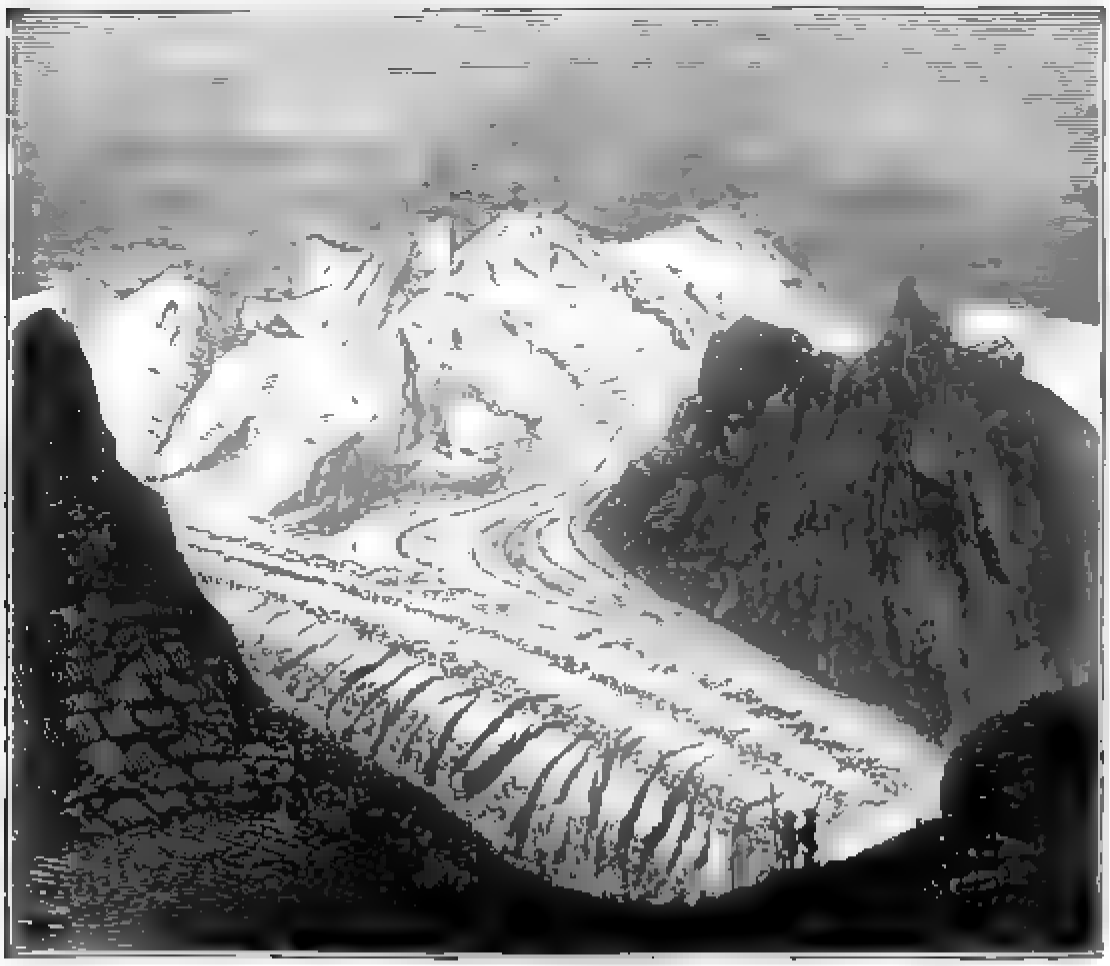
Fig. 948.—Part of the glacier district of Mt. Blanc, the lighter middle portion of the map 16 miles long, out of 23 miles the whole length; river on the northwest side, the Arve in the valley of Chamouni, and that on the southeast side, the Doire; B, Mt. Blanc; G, Aiguille du Géant, J, the Jardin, T, Aig. du Tour, V, Aig. Verte, a, Argentière Glacier; *be*, Brenva Gl., *bn*, Buissons Gl., *bs*, Bois Gl.; *g*, Géant or Tacul Gl., *l*, Leschaux Gl.; *m*, Mer de Glace, upper part of the Bois Glacier; *mg*, Miage Gl.; *ta*, Talèfre Gl.; *tr*, Tour Gl., *tt*, Trient Gl.

Fig. 949.—Section of the Mer de Glace near *m* of fig. 948, or opposite Trelaporte, 950, section of same near *bs* of fig. 948, or opposite Montanvert; 951, View of the Rhone Glacier; 952, profile of same, *c*, *c*, etc. being the transverse crevasses, fading out, and becoming curved after passing the cascade at *mm*.

the *Mer de Glace*. In fig. 949, the bands correspond to different tributaries of this glacier, and the broadest one to the right is that of the Géant Glacier.

4. *General appearance*.—Fig. 953 is a reduced copy of a sketch in Agassiz's great work, representing the Glacier of Zermatt, or the Görner Glacier, in the Mt. Rosa region. This grand glacier receives

Fig. 953.



Glacier of Zermatt, or the Görner Glacier.

some of its tributaries from the right, but the larger part beyond the Riffelhorn, the near summit on the left. The dark bands on the glacier are lines of stones and earth, called *moraines*. The longitudinal lines on fig. 949 represent moraines on the Mer de Glace. The ice of a glacier is intersected by fractures or *crevasses* made by its movement through the irregular valley.

Glaciers descend slopes of all angles. There are cataracts and cascades among them as well as among rivers. One of the large tributaries of the Mer de Glace, the Glacier du Géant (*g*, fig. 948), descends in an immense ice-cascade from the plateau of the Col du Géant into the valley below. The Glacier of the Rhone—one

of the grandest in the Alps—is another ice-cataract. As the glacier commences its steep descent, it becomes broken across, and thus great sections of it plunge on in succession, separated partly by profound transverse chasms. Fig. 951 gives the outline of the lower part of the glacier, *am* being the cataract, *mb* its terminal portion or foot, from the extremity of which the river Rhone issues, and *c*, *c*, *c*, transverse crevasses of the cascade. The same is shown in profile in fig. 952, in which *c*, *c*, etc. are the transverse crevasses.

Other glaciers in some of the higher valleys of the Alps reach the edge of a precipice to descend, perhaps thousands of feet, in a crashing *avalanche*, in which the ice is broken to fragments.

5. *Formation of Glaciers.*—The uppermost portion of a glacier consists of snow and frozen mist, deposited in successive portions, and usually more or less distinctly stratified. This part is called the *névé*. At a lower limit, the snow becomes compacted by pressure into ice, owing to the depth of the accumulations; and here the true glacier portion begins. Below the limit of perpetual frost there is occasional melting in summer, with alternate freezing; and this process aids in changing the mass, as well as the surface-snow, to ice. The stratification of the névé is not generally distinct in the icy glacier.

The following circumstances are essential to, or influence, the formation of glaciers.

(1.) There must be an elevation, or range of heights, above the line of perpetual congelation.

(2.) Abundant moisture is as important as for rivers; and hence one side of a chain of mountains may have glaciers, and not the opposite.

(3.) A difference of temperature between summer and winter is requisite; for otherwise the snows will be melted to the same line throughout the year, and will not descend much below the line of perpetual congelation.

The level of perpetual congelation, and the distance to which glaciers descend, depend on the mean temperature and moisture of the region, and especially the mean temperature of summer as contrasted with that of winter. The height of the snow-line, or that of perpetual congelation, is that in which 32° F. is the *summer* temperature. Below this runs the year-line of 32° F., along which 32° is the mean *annual* temperature. Still below this lies the glacier-limit,—that is, the lowest limit of the glacier. At Mont Blanc, the *snow-line* is 2000 feet *above* the 32° year-line, and the *glacier-limit* is 4500 to 5300 feet *below* it, or 9000 feet above the sea. In the Pyrenees, the snow-line is also 2000 feet *above* that of 32°; in the Caucasus,

2500 feet; in some parts of the Arctic, 3500 feet; on the south side of the Himalayas, 2000 feet, and on the north, 2600; while in the equable climate at the equator in the Andes, the *snow-line* is 1000 feet *below* the year-line of 32°. In Norway, the *glacier-limit* is 4000 feet below the line of 32°.

The lower limit of a glacier sometimes varies several miles in the course of a series of years. A succession of moist years increases the thickness of the glacier, and thereby its tendency downward; while dry years have the reverse effect. If the moist years have also long, hot summers, the descent and lengthening of the glacier will be further promoted,—since glaciers move most rapidly in summer. But hot, dry years would shorten it, by diminishing the ice, and especially at the lower end.

Lowering the mean temperature of a place by cooling the summers would lower the glacier-limit. Great Britain and Fuegia are in nearly the same latitude; and yet in Fuegia the snow-line is only 3000 feet above the sea. If, by any means, the climate of Great Britain could be reduced to that of Fuegia, it would cover the Welsh and Irish mountains with glaciers that would reach the sea, the snow-line being but 1000 to 2000 feet above it; and the same cause would place the snow-line in the Alps at 5000 to 6000 feet above the sea, instead of 9000. This change of temperature involves a removal of tropical sources of heat, or an increase of arctic sources of cold. The diversion of the Gulf Stream by the submergence of Darien has been thought of as a means for the former; but it unfortunately leaves the winds blowing in their old direction, and these cannot be so easily managed. An increase of arctic lands by such elevations as have taken place in former times would accomplish the latter.

6. *The law, rate, and method of flow.*—The *law of flow* is essentially that of rivers. There is friction along the bottom and sides of the glacier, and cohesion in the ice adjoining. The flow is, consequently, most rapid at the surface; and the axis of greatest velocity varies from the medial line to one side or the other of it, according to the bends in the course of the valley. The motion is so slow that there is no atmospheric friction to retard the surface-movement. The greater rapidity of the middle portion is shown by the fact that the transverse ridges made at an ice-cascade, like that of the Rhone, and the lines of earth and sand in the chasms, become afterwards arched in front, as shown in fig. 951, in which the crevasses *c* are at first transverse, but curve below the cascade. The arch is sometimes very much elongated, almost to a triangular form, as in the Géant portion of the Mer de Glace. This is well illustrated in figs. 949, 950, from Tyndall: the right-hand half of the figure corresponding to the Géant Glacier (the cascade in which is alluded to on p. 670) has the transverse bands (carrying dirt and stones) elongated into triangles, while in the other half of the Mer de Glace there

are no such bands, as the tributaries making it do not descend in cascades. (Tyndall.) This difference of velocity between the middle and sides of a glacier has been proved also by direct experiment.

The *rate of movement* depends, of course, upon the slope. According to different observations, it varies from five to over fifty inches a day; and in some places a glacier may be so embayed as to lie almost without motion. A rate of eight to ten inches a day is most common: it is equivalent to 243⅓ to 304 feet a year, or one mile in about twenty-two to seventeen years.

Forbes deduced, from his measurements made at two stations on each of the Bois and Bossons Glaciers, the following results. The first station on the Bois Glacier was near its upper part, where the rapidity is unusually great, and the other near its lower extremity.

	Bois I.	Bois II.	Boss. I.	Boss. II.
Motion from Nov. '44 to Nov. '45..	847.5 ft.	220.8 ft.	657.8 ft.	489.1 ft.
Mean daily motion....................	27.8 in.	7.3 in.	21.6 in.	16.1 in.
Mean daily motion in summer, April to October....................	37.7 in.	9.9 in.	28.0 in.	22.2 in.
Mean daily motion in winter, October to April....................	19.1 in.	4.7 in.	15.8 in.	10.7 in.

This table shows, further, that the rate of motion is about twice as great in summer as in winter.

The maximum in July at the upper station on the Bois Glacier was 52.1 inches; in December, 11.5 inches. The rapidity at the same place is not always the same in different years. Thus, at one station on the Mer de Glace, Forbes obtained for the daily motion in 1842–43, 1843–44, 1844–46, the amounts 8.56, 9.47, 10.65 inches. A knapsack lost in the Talèfre Glacier (*t*, in fig. 948) after ten years was found 4300 feet distant; the slope here of this high glacier was 14° 55′ (Forbes).

The rate (1) at the upper surface, (2) half-way to the bottom, and (3) at the bottom, was found by Tyndall to be in one case 6 inches, 4.59 inches, and 2.56 inches, in a day; and the rapidity at the middle above, to be one-half faster than along the sides.

The *power of motion* in a glacier depends on—

(1.) The capability it has, to a limited extent, of sliding along its bed, but only portions at a time.

(2.) A degree of plasticity in ice, in consequence of which the glacier can adapt itself to any uneven surface; for ice at a temperature near 32° F. may be moulded by pressure into almost any shape. A heavy oblong mass supported at one end may be bent even into a short arch by its own weight. Kane mentions in his "Arctic Explorations" the case of one table of ice, eight feet thick and twenty or more wide, supported only at the ends, which, between the middle of the months of March and May, became so deeply bent

that the centre was depressed five feet. The temperature in March was below zero, and during the interval it was at all times many degrees below the freezing-point.

(3.) The facility with which ice breaks and mends its fractures by *regelation;* that is, by a freezing together again of the surfaces that may be in contact. This principle, first brought forward by Tyndall, is far the most important of the three here mentioned. Any one may test it by breaking a piece of ice and then putting the parts together again: in a few seconds they will be firmly united. A glacier moves on, breaking and mending itself through its whole course. The multitudes of fractures made on steep slopes may all disappear below when the motion becomes slow and the ice feels the pressure from above.

Along the sides of a glacier, especially when passing prominent angles in the valley, the crevasses are deep and numerous. The ordinary direction of these crevasses is obliquely up stream, or at an angle of forty to fifty degrees with the margin, being at right angles, nearly, to the lines of greatest tension in the descending glacier. The crevasses at a bend form especially on the convex side of the stream, the ice undergoing a stretching on that side and a compression on the opposite. There are also deep *transverse* crevasses, and others of irregular courses, made when a glacier is forcing its way through narrow passes in a valley, and when descending rapid slopes. Afterward, on reaching a border-portion of the valley, the ice may return to a solid mass with a comparatively even surface, having fractures only towards the sides. Forbes mentions one chasm 500 feet wide extending quite across the Mer de Glace.

7. *Structure induced by the movement of a glacier.*—The ice of a glacier is often vertically laminated parallel to its sides, and sometimes so delicately so that the ice appears like a semi-transparent striped marble or agate. The layers are alternations of cellular (or snowy) ice and clear bluish solid ice. The melting of the surface sometimes leaves the more solid layers projecting, as mentioned by Guyot,—one of the first who noticed this peculiarity of glaciers. The structure is due to the tension or pressure to which the glacier is subjected in making its way between the enclosing walls of a valley, especially where there is a contraction in width, or a projecting point around which a strain is produced. It may also be formed when two great glaciers unite, the pressure between the meeting streams being here the cause.

The resistance to motion in a glacier is not continuously overcome, as in the case of a perfect fluid, but intermittently. There

are intervals of rest and accumulation, and then a yielding. The movement is, therefore, oscillatory, with the intervals, it may be, of only a few minutes, or a few hours, or more. Such an oscillatory action is especially calculated to produce a laminated structure. As Tyndall has observed, the air-cells appear to have been in part expelled from the bluish layers by the pressure, and in part to have been obliterated by an incipient liquefaction and refreezing of the layer.

In the lower part of the glacier of the Rhone, the laminated structure is produced, according to Tyndall, between the capes *m* and *n* (fig. 951). It appears first in the section *s*, and is fully developed in the following one, *s′*. The radiating lines crossing the concentric lines of tension represent crevasses.

This lamination is very distinct over parts of most glaciers. It is well shown either side of the middle of the Mer de Glace; it gives a longitudinal structure to the central portions of the Aar Glacier below the junction of its two great branches, the Finster-Aar and the Lauter-Aar; it characterizes, according to Forbes, the whole of the Brenva Glacier.

2. Transportation and erosion.

1. *Transportation.*—The *moraines* of glaciers are made from (1) the stones and earth which fall from the cliffs along their borders; (2) the material received from falling avalanches; (3) that which is taken up by the ice from the surface of the valley against which they move. They form in all the stages of progress of a glacier, though usually the least in the region of the névé, where the peaks are often small compared with the extent of snow. The surface in this upper part is always peculiarly white and clean, owing to the frequent falls of snow.

From their mode of origin, it follows that moraines are situated primarily along the margin of a glacier. But, when two glaciers coalesce, the two uniting sides join their moraines in one; and this one is remote from the borders, and may be central—as in the glacier of the Aar—if the two coalescing streams are about equal. It follows from the above that the number of moraines on a glacier can never exceed the number of coalesced glaciers by more than one.

In the Glacier of Zermatt, the nearest moraine in the view (fig. 953) is that of the Riffelhorn; the second is a union of moraines of the Görnerhorn and Porte Blanche; the third, a union of two moraines from two Mt. Rosa Glaciers; the fourth, the great moraine of the Breithorn, the summit in the middle of the view. Other

moraines may be seen on the distant part of the glacier. In fig. 949, representing a section of the Bois Glacier near Trelaporte, there are six distinct moraines.

Toward the lower extremity of a glacier (as shown in fig. 950, from the lower part of the Bois Glacier) the several moraines usually lose their distinctness through the melting of the ice; for this brings the stones and earth that were distributed at different depths to one level, and thus produces a coalescence of the whole over the surface.

The stones are both angular and rounded, the former far the more abundant. Many are of great magnitude. One is mentioned containing over 200,000 cubic feet, or equal in size to a building 100 feet long, 50 wide, and 40 high.

At the glacier of the Aar, the central moraine is raised 100 to 140 feet above the general surface either side; but this is partly owing to the pressing up of the ice itself by the mutual pushing of the two combined glaciers of which it is made. The breadth where narrowest is 250 feet; and from this it increases to 750 feet halfway to the termination of the glacier, and to treble this below.

The final melting of a glacier leaves vast piles of unstratified stones and earth along its sides, toward and about its lower extremity. The stream which proceeds from the glacier works over all that comes within its reach, carrying it onward down the valley, and making deposits on its banks which are usually more or less perfectly stratified.

2. *Erosion.*—(1.) The movement of a glacier is attended with so much wrenching of the ice, that the blocks generally have their angles more or less blunted by mutual attrition, and many of the stones are rounded.

(2.) As the glacier has its sides and bottom here and there set with stones of large and small size, it is a tool of vast power as well as magnitude, scratching, ploughing, and planing the rocks against or over which it moves. Besides this, it pushes along gravel and stones between itself and the rocks, with the same kind of effect. The rocky cliffs and ledges in the vicinity of the glaciers are in many places furrowed, planed, and rounded over their whole exposed surface from this agency. The furrowings or gougings have a common direction; but there are sometimes two or more directions, indicating glacier-movements of different periods.

(3.) The stones which have produced the furrowing are sometimes scratched themselves.

Other facts connected with this subject are mentioned on page 535.

Glaciers, as these facts show, are also powerful agents in widening and deepening valleys.

The snow and ice of Alpine valleys often cause, indirectly, violent erosion and transportation of material by damming up streams. In no other way can barriers be thrown so readily across profound valleys; and the deluges caused by the accumulated waters when they break loose are often very destructive. The Alps are full of examples.

4. ICEBERGS.

A glacier on a sea-coast often stretches out its icy foot into the ocean, and when this part is finally broken off by the movement of the sea, or otherwise, it becomes an iceberg. Greenland is the great region of icebergs, no less than of glaciers. They carry away the stones and earth with which the glacier was covered during its land-progress, and transport them often to distant regions, whither they are borne by the polar oceanic currents.

Dr. Kane describes the great pack of icebergs that occupies the centre of Baffin's Bay, and mentions that some were 300 feet high, and large numbers over 200 feet. There were 280 icebergs of the first magnitude (the most of them over 250 feet) in sight at one time.

In the Antarctic, Captain Wilkes observed a long ice barrier, having a height above the sea of 150 to 200 feet; and some of the bergs were 300 feet high. The ice of the barrier was stratified; and, according to Wilkes, this was owing to the constant increase from the freezing mists over it.

As the specific gravity of ice is 0.918 (at 32° F.), the proportion of the mass out of water is about *one-twelfth*.

The icebergs of the Atlantic melt mostly about the Banks of Newfoundland, or between the meridians of 44° and 52°. They have been observed in this ocean as far south as 36° 10′.

Icebergs are (1) a means of transporting stones and earth from one region to another (see p. 542). (2.) When grounded on rocks they may scratch the surface; but closely-crowded and regular scratches like those of glaciers over large areas could hardly be made. The currents of Baffin's Bay flow southward on the west side and northward on the other,—which would give great irregularity there to the scratches of grounded bergs. An iceberg "rocked by the swell of the sea, and sometimes turning over," could not be good at scoring submerged rocks. Moreover, these rocks, in the seas in which icebergs melt and drop their freight of stones, would seldom be uncovered.

4. FORMATION OF SEDIMENTARY STRATA.

In recapitulation, sedimentary strata have been formed—

1. *By the waters of the sea.*

(1.) Through the sweep of the ocean *over the continents when barely or partly submerged,—making* (*a*) sandy or pebbly deposits near or at the surface where the waves strike, or at very shallow depths where swept by a strong current; (*b*) argillaceous or shaly deposits near or at the surface, where sheltered from the waves, and also at considerable depths out of material washed off the land by the waves or currents; (*c*) but *not making* coarse sandy or pebbly deposits over the deep bed of the ocean, as even great rivers carry only silt to the sea; and *not making* argillaceous deposits over the ocean's bed except along the borders of the land, unless by the aid of a river like the Amazon, in which case, still, the detritus is mostly thrown back on the coast by the waves and currents.

(2.) Through the waves and currents of the ocean acting *on the borders of the continent* with the same results as above, except that the beds have less extent.

(3.) Through marine life, and mainly Mollusks, Radiates, and Rhizopods, affording calcareous material for strata, and some Infusoria, siliceous material. All rocks made of corals and the shells of Mollusks, excepting the smallest, require the help of the waves at least to fill up the interstices (see p. 619); but Rhizopods and siliceous Infusoria may make rocks in deep water, by accumulation, which are in no sense sedimentary.

2. *By the waters of lakes.*—Lacustrine deposits are essentially like those of the ocean in mode of origin, unless the lakes are small, when they are like those of rivers.

3. *By the running waters of the land.*—(1.) Filling the valleys with alluvium, and moving the earth from the hills over the plains. (2.) Carrying detritus to the sea or to lakes, to make, in conjunction with the action of the sea or lake waters, delta and other sea-shore accumulations.

4. *By frozen waters.*—(1.) Spreading the rocks and earth of the higher lands over the lower, and, in the process, bearing on blocks of great size, such as cannot be moved by other means. (2.) Carrying rocks and earth from the land to the ocean, either to the sea-shore, making accumulations in lines or moraines, or to distant parts of the ocean, as from the Arctic to the Newfoundland Banks; and thus contributing to deep or shallow water or shore sedimentary accumulations, distinguished for the irregular intermingling of huge blocks of stone, pebbles, and earth.

5. EXTENT AND TOPOGRAPHICAL EFFECTS OF EROSION OVER THE CONTINENTS.

1. **Extent of erosion.**—The outlining of mountain-ridges and valleys has been in part produced by subterranean forces fracturing the strata; but the final shaping of the heights is due to erosion. This cause has been in action from the earliest time, and nearly all rocks not calcareous have resulted from the erosion of pre-existing formations. The Appalachians have probably lost by denudation more material than they now contain. Mention has been made of faults of even twenty thousand feet along the course of the chain from Canada to Alabama. In such a fault one side is left standing twenty thousand feet above the other, equivalent in height to some of the loftier mountains of the globe; and yet now the whole is so levelled off that there is no evidence of the fault in the surface-features of the country. The whole Appalachian region consists of ridges of strata isolated by long distances from others with which they were once continuous. Fig. 103 represents a common case of this kind. It is supposed by some geologists that the Appalachian and western coal-fields were once united, and that, in western Ohio and other parts of the intermediate region, strata thousands of feet deep, from the Lower Silurian upward, have been removed, and this over a surface many scores of thousands of square miles in area. This view has been questioned on a former page. Whether true or not, there is no doubt that the anthracite coal-fields of central Pennsylvania were once a part of the great bituminous coal-field of western Pennsylvania and Virginia (fig. 559, p. 323). They now form isolated patches, and formations of great extent have been removed over the intervening country. The Illinois coal-region is broken into many patches in consequence of similar denudation and uplifts.

In New England there is evidence of erosion on a scale of vast magnitude since the crystallization of its rocks. On the summit-level between the head-waters of the Merrimac and Connecticut, there are several pot-holes in hard granite; one, as described by Professor Hubbard, is ten feet deep and eight feet in diameter, and another twelve feet deep. They indicate the flow of a torrent for a long age where now it is impossible; and the period may not be earlier than the Post-tertiary. Many other similar cases are described by Hitchcock.

These examples of denudation are sufficient for illustration.

Europe and the other continents furnish others no less remarkable, and to an indefinite extent.

2. **Topographical effects of erosion.**—The topographical effects of erosion depend on several conditions,—as (1) the durability of the rocks, (2) their structure, and (3) their stratification.

1. *Durability of the rocks.*—Granite is well known to run up into lofty needles (or *aiguilles*), as in the Alps and, still better, the Organ Mountains of Brazil and some peaks in the Shasta Mountains of California. But there are varieties crumbling easily on exposure, and these occur only in broad, massive elevations. The hard argillite (roofing-slate) often forms bold, craggy heights, while soft argillaceous shales make only tame hills and undulating plains.

The refractory quartzites and grits, which make little or no soil, stand up in rude piles and massy brows of nearly bare rock.

2. *Structure.*—When there are no planes of structure, as in true granite, the rock may rise into lofty peaks with rounded surfaces. Slow denudation goes on over all sides of the peak, either from trickling waters or frosts, and may gradually narrow it into the model *aiguille*. But when the rock has a cleavage-structure like the schists and slates, its heights are rough and angular, and its *aiguilles*, if any are formed, are more apt to be pyramidal than conical.

The joints in slates or sandstones often lead to forms resembling walls and battlements when exposed in cliffs (fig. 88, p. 100). The architectural effect of the columnar cleavages of trap or basalt is shown in fig. 115, p. 118.

3. *Stratification.*—The results with stratified rocks differ according to (1) the position of the strata, and (2) their nature.

If the strata are *horizontal*, or nearly so, and *hard* and *similarly so* throughout, the elevations have generally table summits, with vertical rocky brows facing the lower lands. The river-valleys are profound, and often inaccessible for long distances, owing to the boldness of the precipices. Some varieties of these valleys are shown in figs. 940, 941. Other topographical effects are described in the remarks on the erosion of valleys, p. 635. If the rock is firm, like most limestones, it may rise into lofty, few-angled summits, especially when erosion has been preceded by fractures; as in the Alpine heights of the Wetterhorn and its associates near Grindelwald, in the Bernese Oberland.

If *horizontal*, or nearly so, but of *unequal hardness*, the softer strata are easily worn away, undermining the harder strata; the table-lands have a top of the harder rock, and the declivities are usually banded with projecting shelves and intervening slopes. Figs. 954, 955 represent the common character of such hills. A number are shown in fig. 940; in the Colorado region they have been called *Mesas*, from the Spanish for *table*.*

Fig. 954.

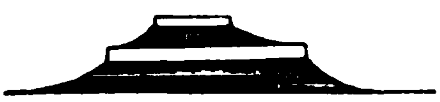


Fig. 955.

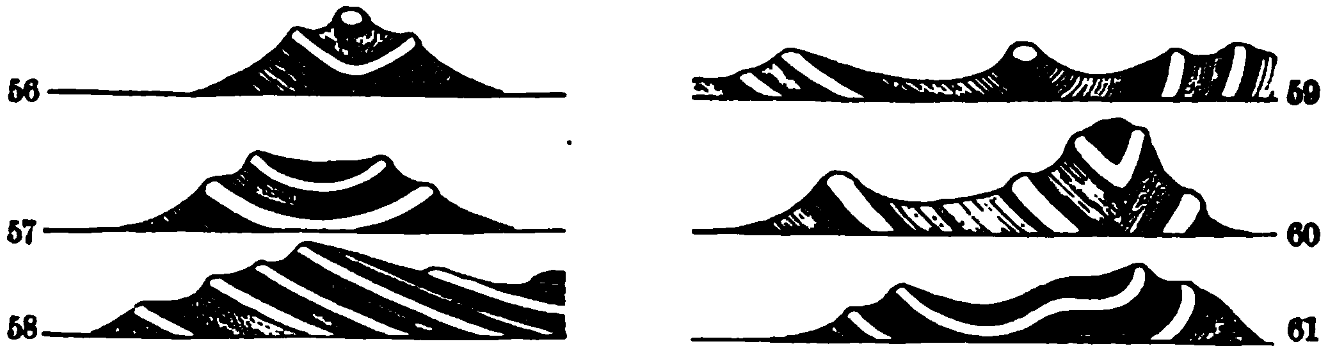
* For figures 954–965 and the views they illustrate, the author is indebted to the volume on "Coal and its Topography," by Lesley. In a long chapter, on "Topography as a science," this author has given the results of extensive personal observation.

When the beds are *inclined* between 5° and 30°, and are alike in hardness, there is a tendency to make hills with a long back slope and bold front; but with a much larger dip, the rocks, if hard, often outcrop in naked ledges.

When the dipping strata are of unequal hardness, and lie in folds, there is a wide diversity in the results on the features of elevation.

Figs. 956, 957 represent the effects from the erosion of a *synclinal* elevation consisting of alternations of hard and soft strata. The protection of the

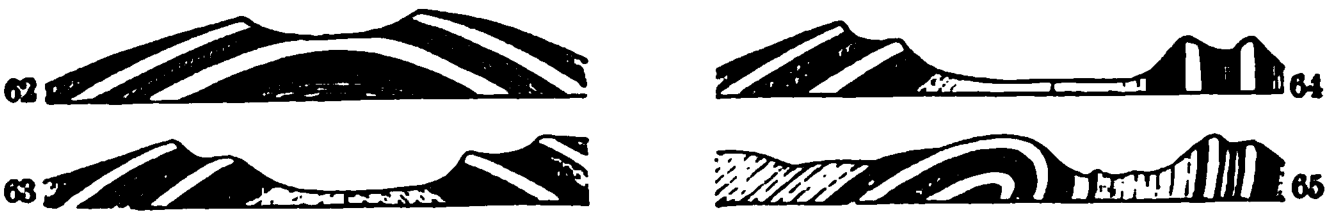
Figs. 956–961.



softer beds by the harder is well shown. This is still further exhibited in figs. 958–961.

Anticlinal strata give rise to another series of forms, in part the reverse of the preceding, and equally varied. Figs. 962-965 represent some of the simpler cases. When the back of an anticlinal mountain is divided (as in figs. 962, 963, 964), the mountain loses the anticlinal feature, and the parts are

Figs. 962–965.



simply *monoclinal* ridges. In fig. 965, the anticlinal character is distinct in the central portion, while lost in the parts either side. In fig. 965 to the right, a common effect is shown of the protection afforded to softer layers by even a vertical layer of hard rock: the vertical layer forms the axis of a low ridge.

The above are the simple results from the erosion of folded rocks. They serve as a key to the complexities of features common through a large part of the Appalachians, where synclinal and anticlinal axes, as Lesley states, are in numberless complicated combinations, and are rendered doubly puzzling by faults. See, further, pages 104–109, 404–408.

V. HEAT.

1. SOURCES OF HEAT.

The crust of the Earth has three sources of heat:—(1) The Sun; (2) Chemical and mechanical action; (3) The igneous condition of the Earth's interior.

1. *The Sun.*—The Sun (1) causes, and must always have caused, an increase of temperature over the globe from the poles to the equator, as well as a variation of seasons. (2.) In the warmer season it heats the soil to a varying depth, and then, through the colder season, allows it to be chilled. At some depth, varying with the latitude, the heat is uniform the year round: this depth in temperate latitudes at the present time is 25 to 30 feet; under the equator, 3 to 4 feet; in the frigid zone, but little more than under the equator. (3.) The amount of heat derived from the sun, and determining climate, varies with the extent and distribution of the land (p. 45), and with its elevation,—a wide extent of high or polar lands being an occasion of cold, and of low or tropical lands an occasion of warm, climates.

2. *Chemical and mechanical action.*—All chemical changes in which there is condensation, as in liquids becoming solids, or gases liquids, or either increasing their density, evolve heat. This is often an effect of the natural decomposition of minerals or of vegetable or animal matter.

All mechanical action, as the beating of waves on a coast, the falling of water in cascades or rain, the shaking of earthquakes, sliding of rocks, motion of the atmosphere in winds, produces heat whenever the action meets with resistance, on the principle that motion corresponds to an amount of heat, and that heat appears when the motion ceases. This source of heat has probably produced its effects, although it may be difficult to point them out.

3. *Internal heat.*—According to the results of geological research, *internal heat* exhibits its effects over the whole surface, in volcanoes,—earthquakes,—the metamorphism and consolidation of rocks,—the elevation and subsidence of the earth's crust, raising and depressing the continents or portions of them as well as islands, and making mountain-chains.

The proofs of the existence of a source of heat within the earth are the following:—

1. The spheroidal form of the earth is proof of original fluidity, and therefore of a subsequent cooling over the exterior from a state of igneous fluidity.

2. The lowest rocks reached by geological exploration are crystalline rocks,—rocks which, if not once in igneous fusion, have at least been crystallized through the aid of heat, and heat that must have reached them from below.

3. Borings for Artesian wells and shafts in mines have afforded a means of taking the temperature of the earth at different depths;

and it has been uniformly found that after passing the limit of surface-action (p. 682) the heat quite regularly increases. The rate is 1° F. for 50 or 60 feet of descent. At the Artesian well of Grenelle, a temperature of 85° F. was obtained at 2000 feet, equivalent to 1° F. for every 60 feet of descent. In Westphalia, at Neusalzwerk, in a well 2200 feet deep, the temperature at the bottom was 91° F., or 1° F. for 50 feet of descent. At Pregny, near Geneva, a depth of 680 feet gave 63° F.

It has been proposed to make a tropical climate in the Garden of Plants by taking the heat from the earth's interior. Arago and Walferdin have estimated that at a depth of 3000 feet the water would have a temperature of 200° F., "sufficient not only to cheer the tropical birds and monkeys of the Zoological Gardens and the hot-houses and green-houses of the establishment, but to give warm baths to the inhabitants of Paris."

At Yakutsk, Siberia, Magnus found a gain of 15° F. in descending 407 feet, equal to 1° F. for 27 feet.

The rate 1° F. for 50 feet of descent in the latitude of New York would give heat enough to boil water at a depth of 8100 feet; and 3000° F., the fusing-point of iron, at a depth of about 28 miles. As the ratio would not be an arithmetical one, since the fusing-point of any substance is increased by pressure, the depth of fusion would exceed this amount. But the facts still prove that the earth has a source of heat within.

4. The warm climate over the whole globe in the early ages, and the serial diminution of heat with the progress of time until now, when there is a frigid Arctic, corresponds with the idea of a cooling globe. This cause appears to have acted conjointly with that connected with the geographical distribution and height of the land, referred to on the preceding page.

At present, very little of the interior heat reaches the surface. According to Poisson, the amount is only *one-seventeenth* of a degree Fahrenheit; and to reduce this amount one-half, or to *one-thirty-fourth*, would now require 100,000,000,000 years. Mr. Hopkins, of England, has stated that, supposing this the only mode of cooling, it must have required as long a time as this to have diminished the temperature the last two or three degrees of its decrease.

5. The wide distribution of volcanoes over the globe is evidence of internal heat. Volcanoes, extinct or active, border the Pacific from Fuegia to the Arctic; through the Aleutian Archipelago to Asia; down the Asiatic coast, through Kamtchatka, Japan, and the Philippines, to New Guinea, New Hebrides, and New Zealand; and they constitute half of the islands of this ocean, two of which, in Hawaii, are nearly 14,000 feet high. This volcanic region is equal

to a whole hemisphere, and therefore sufficient evidence as to the nature of the whole globe. Volcanoes occur also through Java and Sumatra; in central Asia in the Thian-chan Mountains; about the Mediterranean and Red Seas; in western Asia, and southern, central, and southwestern Europe; in Iceland, and the West Indies.

The ejection of melted rock through fissures has taken place over all the continents; in Nova Scotia, Canada, New England, New Jersey and the States south, the region of Lake Superior, the Rocky Mountains, and western America; in Ireland, Scotland, and various parts of Europe; and so over much of the globe.

These evidences combine to prove that the interior of the earth is a source of heat.

It is, however, still an open question whether the internal heat is that of fusion; or, if there is fusion, whether the whole interior is fused, or whether there are only interior seas of liquid rock; or, if the interior is fused, what is the thickness of the crust. From a survey of the facts, the most probable conclusion is that the crust is not over 100 miles thick. Within the crust there may be isolated seas of melted rock, feeding volcanoes.

Professor Perrey, of Dijon, has inferred from his extended researches that there is a periodicity in earthquakes dependent on *tides* in the internal igneous material of the globe. (See beyond, on Earthquakes.)

Recent mathematical calculations have made the thickness of the crust to be at least 800 miles. But the results of figures should not be allowed to suspend or throw discredit on observations until it is absolutely certain that all the data required for them are known and thoroughly understood in their various bearings.

2. EFFECTS OF HEAT.

The effects of heat considered in this place are the following:—

1. Volcanoes and related phenomena; 2. Non-volcanic igneous ejections; 3. Metamorphism and production of mineral veins.

Heat is also one at least of the causes of the elevation of mountains, and of earthquakes. These topics are considered in the following chapter. It is an important agent also in most chemical changes; and hence its effects belong in part to *Chemical Geology*.

1. VOLCANOES.

The facts relating to volcanoes are here presented under the following heads:—(1) General nature of volcanoes, and their geographical distribution; (2) Kinds of volcanic cones; (3) Volcanic action;

(4) Origin of the forms of volcanic cones; (5) Subordinate volcanic phenomena; (6) Source of volcanoes.

1. General nature of volcanoes, and their geographical distribution.

1. **Volcanoes.**—Volcanoes are mountains or hills, of a more or less conical shape, in a state of igneous action, and consequently emitting *vapors*, and occasionally melted rock or *lava*, with showers of fragments or *cinders*, from a central opening called the *crater*. They are conduits of fire, opening outward from within or beneath the earth's crust. An *extinct* volcano is a volcanic mountain that has ceased to be active,—the body with the fire out.

The lavas flow out either over the edge or lip of the crater, or, more commonly, through fissures in the sides or about the base of the mountain. The cinders are thrown upward from the vent or crater to a great height, as a jet of sparks or fiery masses, and fall around in cooled particles or fragments, which are only granulated lava: they may build up a conical elevation around the vent, or be carried to a distance by the winds.

When rain or moisture from any source descends with the cinders, the mass forms *tufa*,—a stratified, somewhat earthy, granular, and rather soft rock, of gray, yellowish-brown, and brownish colors.

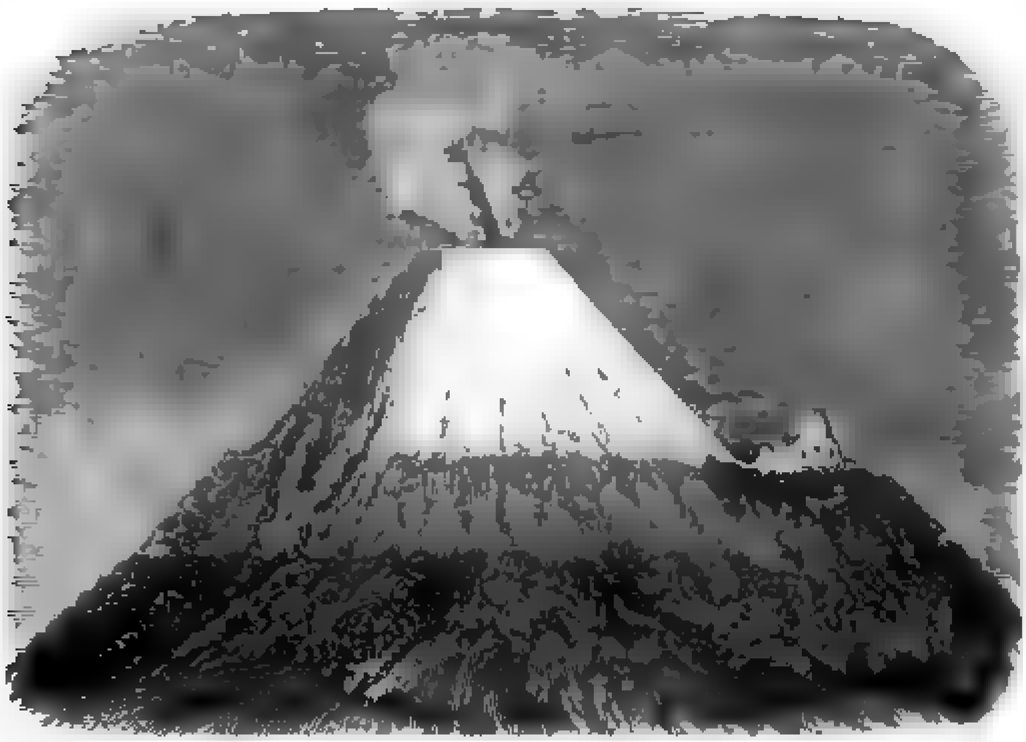
2. **Geographical distribution.**—Volcanoes occur (1) over the border regions of the continents,—that is, the regions between the oceans and the summit of the border range of mountains, as between the Pacific and the summit of the Rocky Mountains; (2) in the continental islands, or those near sea-coasts; (3) in oceanic islands, nearly all of which, excepting a few of very large size and the coral islands, are throughout volcanic,—and the coral islands have probably a volcanic basis. (4.) Volcanoes are mostly confined to the borders of the larger ocean, the Pacific and the vicinity of the seas separating the northern from the southern continents, namely, the West Indies between North and South America,—the Mediterranean between Europe and Africa,—the Red Sea between Asia and Africa,—the East Indies between Asia and Australia. There are but few about the Atlantic, excepting those of the islands; and over the interior of continents, remote from the regions mentioned, they are almost unknown.

(5.) Volcanoes are very commonly in linear series or groups.

1. *Borders of the Pacific.*—The Pacific is almost completely belted with volcanic mountains. They occur in Fuegia, the southern extremity of the Andes; in Patagonia; 32 in Chili,—that of Aconcagua 23,000 feet high; 7 or 8 in Bolivia

and southern Peru,—Arequipa 18,000 feet: 19 or 20 about Quito, nearly all over 14,000 feet, and among them Cotopaxi, 18,876 feet in altitude; in Central America there are 39; in Mexico, 7 of large size, with others smaller; in California, Oregon, and northwest America, 12, making a lofty series of snowy sum-

Fig. 966.



Volcano of Cotopaxi.

mits, 12,000 to 18,000 feet high,—St. Helen's, in Oregon, 16,000 feet; Mt. Hood, 14,000; Mt. Shasta, 14,000. In the Aleutian Islands, which form a curve like a festoon across the Northern Pacific, there are 21 islands with volcanoes; in Kamtchatka, 15 to 20; in the Kuriles, 13; in the Japan group, 24, some 10,000 feet high; in the Philippines, 15 to 20; several along the north coast of New Guinea; a number in New Zealand; in the Antarctic, on the parallel of 76° 5', and near the meridian of 168° E., Mts. Erebus and Terror, 12,400 and 10,900 feet high, both in full action when seen by Ross in 1841; and more to the east, south of Cape Horn, Deception Island and Bridgeman's.

2. *Over the Pacific.*—At the Hawaiian Islands, there are remains of ten or more volcanic mountains, and two on Hawaii are now active,—Mt. Loa, 13,760 feet high, and Mt. Hualalai, about 10,000 feet; while Mt. Kea, on the same island, 13,950 feet high, has not been very long extinct (fig. 24, p. 31, and fig. 973, p. 695). There are other volcanic mountains at the Society group, Marquesas, Navigator, Friendly Islands, Feejees, Santa Cruz group, New Hebrides, Ladrones; among which Tauna and Ambrym in the New Hebrides, Tafoa and Amargura in the Friendly group, Tinakoro in the Santa Cruz group, and two or three in the Ladrones, are in action.

3. *Over the seas that divide the northern and southern continents from one another, and the regions in their vicinity.*—(*a.*) The West Indies, where ten islands are eminently volcanic. (*b.*) The Mediterranean and its borders, as in Sicily

and the islands north; Vesuvius, and other parts of Italy; Spain, central France, Germany, etc., in Europe; the Grecian Archipelago, which contains five volcanic islands,—Santorin, Milo, Cimolos, Polenos, and Misyros; in Asia Minor, where are the Catacecaumene and other volcanic regions; and more to the eastward, towards the Caspian, Mt. Ararat, 16,950 feet high; Little Ararat, 12,800 feet; Demavend, on the south shore of the Caspian, 20,000 feet. (*c.*) The Red Sea, along its southern borders, where there are a number of lofty volcanic summits. (*d.*) The East Indies, where there are 200 or more volcanoes, of which there are nearly 50 in Java alone, according to Dr. Junghuhn, and 28 out of the 50 now active, nearly as many in Sumatra, 109 in the small islands near Borneo, a number in the Philippines, etc.

4. *In the Indian Ocean.*—A few in Madagascar; also the Isle of Bourbon, Mauritius, and the Comoro Islands, and, to the south, Kerguelen Land, etc.

5. *On the Atlantic borders.*—Only in the Bight of Benin on the African coast, where one in the Cameroons Mountains is said to be 14,000 feet high, and the neighboring islands from Fernando Po to Annabon.

6. *In the Atlantic Ocean.*—St. Helena, the Cape Verdes, Canaries, Madeira, Azores, and Iceland. All the islands of the deep part of the ocean (that is, not on the European or American borders) are volcanic.

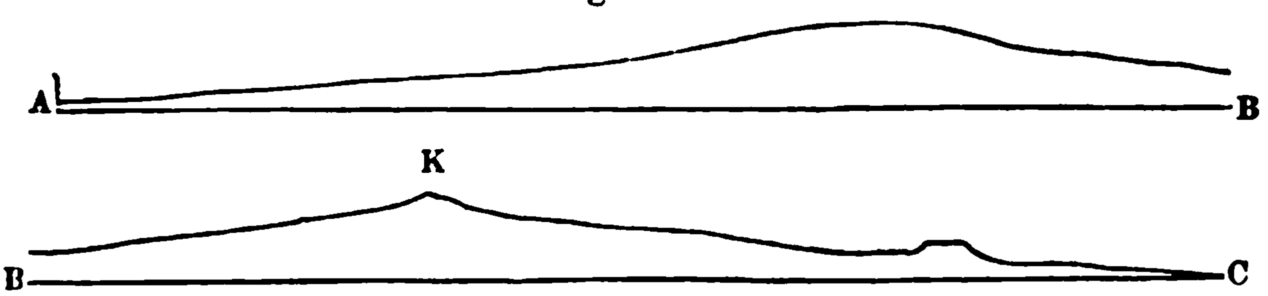
7. *Over the interior of the continents.*—In America, north and south, there are none east of the Rocky Mountains and Andes. In Africa, none are known. In Asia, there is a small volcanic region in the Thian-chan Mountains, at Pe-schan and Turfan, besides hot springs near Alak-tu-kul, and some other spots in that vicinity. In Australia, none are known over the interior, the few observed being situated near its southern border.

2. Kinds of volcanic cones.

As the volcanic mountain is made from its own ejections, it may consist either (1) of *lava alone*; (2) of *tufa alone*; (3) of *cinders alone*; (4) of *combinations of lavas with either cinders or tufas, or both.* The last is the more common kind.

1. *Lava-cones.*—Lavas, when quite liquid, flow off naturally at a small angle. The average slope of lava-cones is, therefore, very gentle,—usually between 3 and 10 degrees.

Fig. 967.

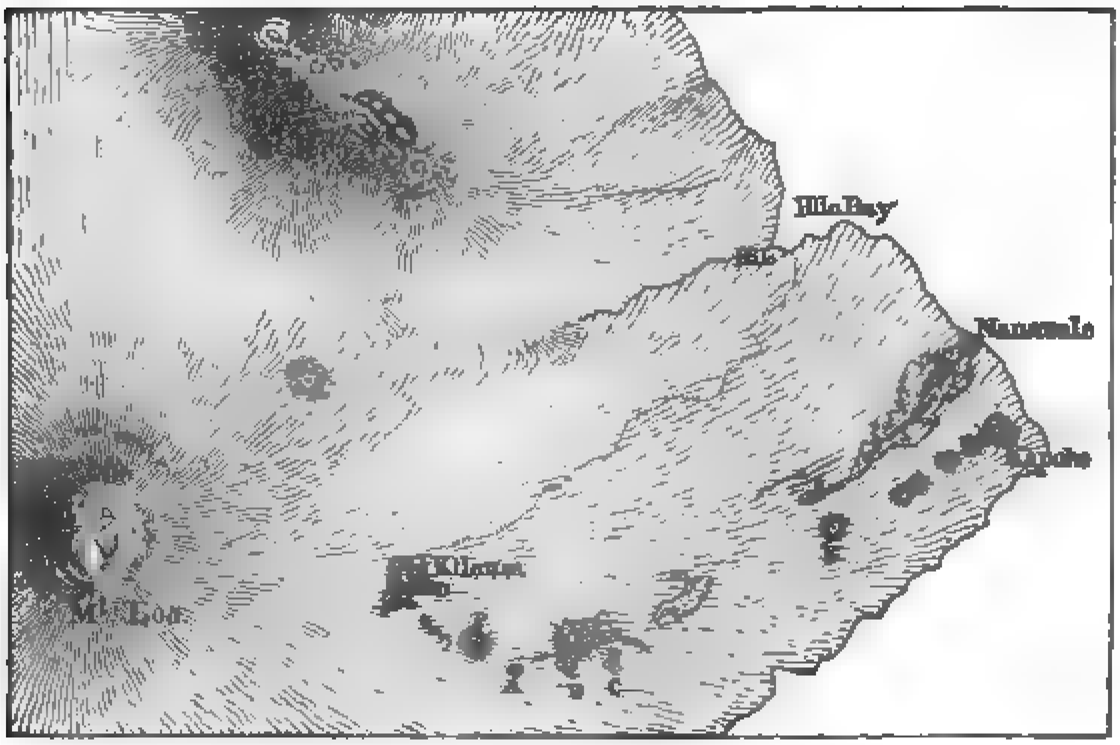


A, B, B, C, profile of Hawaii, as seen from the eastward; L, Mt. Loa; K, Mt. Kea.

The great volcanoes of Hawaii (Sandwich or Hawaian Islands), Mt. Loa and Mt. Kea, shown in the map (fig. 968), and sections of

which are given in figure 967, are mainly lava-cones, and the general slope is 6 to 8 degrees. (These two figures are parts of one pro-

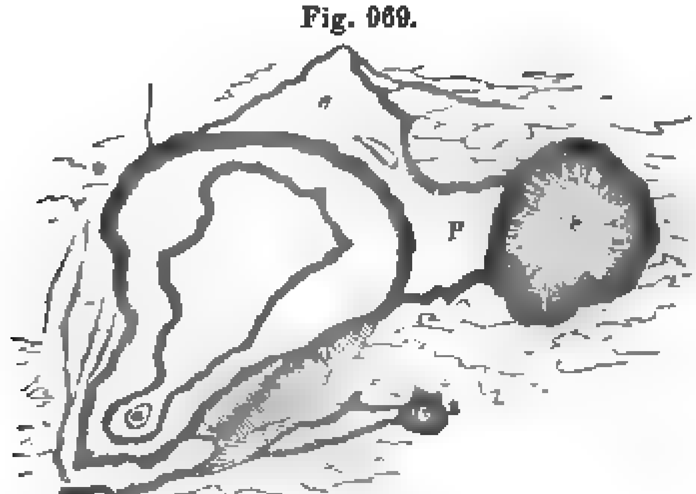
Fig. 968.



Map of part of Hawaii.

file view of the island, the two joining at B.) Etna has a similar

Fig. 969.



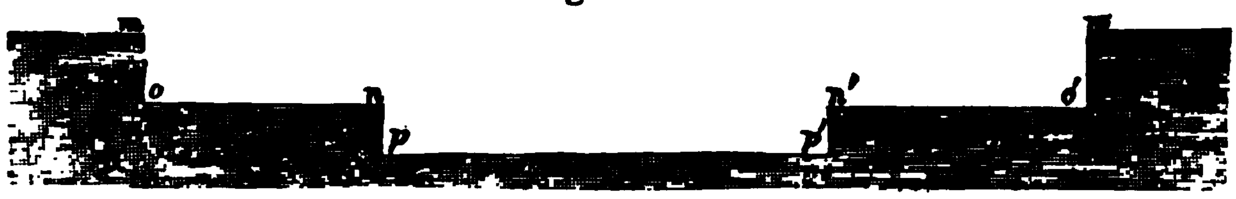
Crater of Kilauea, in 1840. *a*, large boiling lake of lava; at *o* and near *c*, sulphur-banks; *r*, an adjoining small crater; *p*, neck between Kilauea and the crater *r*.

low inclination. A horizontal section of Mt. Loa, 1800 feet below its top, would be nearly twenty miles broad.

In true lava-cones, like Mt. Loa, the *crater* is generally a pit-crater,

—a great depressed area in the surface of the mountain, like a pit or quarry-hole in a plain, as in the summit-crater of Mt. Loa and in Kilauea, the latter 4000 feet above the sea. A larger bird's-eye view of Kilauea (with an adjoining small crater, *r*) is shown in fig. 969, and a vertical transverse section of the same, more enlarged, in fig. 970. The pits have precipitous walls of stratified rocks; for the lavas are in layers, and the layers are nearly horizontal.

Fig. 970.

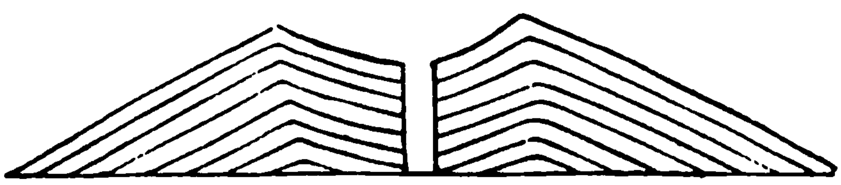


Vertical section of crater of Kilauea, 1840.

At Mt. Loa, the summit-crater is 13,000 feet in its longer diameter, and 780 feet deep. Kilauea is 16,000 feet in its greatest length, 7½ miles in circuit, nearly four square miles in area, and 600 to 1000 feet deep,—the latter after one of its great eruptions. It is as much open to the day as a city of two miles square would be within an encircling wall of 600 feet (the present depth); and the pools of boiling lavas and vapors (one of which is at *a*, fig. 969) may be as leisurely surveyed from the brink as if the objects were gardens and cathedrals.

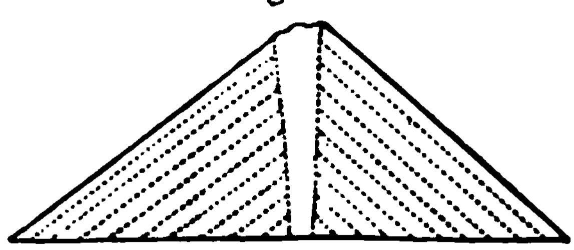
2. *Tufa-cones.*—Flowing mud from a boiling basin, or cinders wet with water and steam, take a larger angle of flow than lavas; and tufa-cones, therefore, have commonly an angle of between 15 and 30 degrees. The layers usually slope inwards towards the bottom of the crater (fig. 971), as well as outwards down the sides. The tufa

Fig. 971.



Section of a tufa-cone.

Fig. 972.



Assumption Island, one of the Ladrones.

has a brownish-yellow color, owing to the action of the steam or hot water on the cinders, peroxydizing part of the iron in the minerals (pyroxene mainly) of the lavas, and making a hydrous peroxyd (p. 65). The *crater* has generally a saucer shape. A tufa-cone on Oahu (called Diamond Hill) has a height of 1000 feet. Such cones are among the results of lateral eruptions about a great volcano near the sea.

3. *Cinder-cones.*—Falling cinders, like sand, may make a declivity of 40 to 45 degrees. The eruption of cinders, therefore, produces a

crater with a narrow throat, a narrow rim above, steep sides, the slope 35 to 45 degrees (fig. 972). If the volcano is in brisk action, the space within the crater is dark with the rising vapors, and the explosions attending the ejection of cinders occur usually at short intervals.

The cone is at first nearly black or brownish black, but, if not soon covered with vegetation, it often becomes, through atmospheric agencies, of a red color, from the peroxydation of the protoxyd of iron in the lava: the peroxyd of iron formed differs from that of the tufa-cone in not containing water, and hence the difference of color. The growth of vegetation tends to change back the red color to brownish black, since the carbon deoxydizes the peroxyd, making protoxyd and carbonic acid.

4. *Mixed cones.*—The cones which, like Vesuvius, are formed partly of lava and partly of cinders or tufa, may have any angle of slope up to 35 degrees. They may be lava below, and terminate in a lofty cone of cinders of 40 to 45 degrees. The *crater* may be nearly like that of the cinder-cone,—a deep cavity, with the walls thin, compared with those of the simple lava-cone. There is no fixed order in the alternations of lavas and cinder or tufa layers: the lavas are apt to prevail most in the early stages of a volcano.

3. Volcanic action.

The agents concerned in volcanoes are (1) lava; and (2) overheated steam and atmospheric air, with vapors of sulphur, and some other gases.

The phenomena are (1) Rising and projectile effects of escaping vapors; (2) Movements of the lavas in the crater; (3) Eruptions.

The facts presented in illustration of this subject are taken mainly from the volcanoes of Kilauea and Vesuvius, both of which have been visited by the author.

1. Agents.

1. **Kinds of volcanic rocks or lavas.**—The fused rock-material is, in all cases, called *lava*. When solidified, it is *lava* still, and is often so termed, whatever its texture; but in general the name is restricted to those volcanic rocks which are more or less cellular. The cellules are usually ragged, and not smooth and almond-shaped like those of an *amygdaloid*. The solid kinds, with rarely a cellule or with none at all, come under the general designation of *volcanic rocks*. A very light cellular lava is a *scoria*, or *volcanic slag*, or is said to be *scoriaceous*.

The principal kinds of volcanic rocks and lavas have been described on pp. 87–89, to which reference may here be made. The most common are *dolerite, doleritic lava, basalt, basaltic lava, clinkstone, trachyte.*

The rock of Vesuvius is *leucitophyr*, it containing the white mineral *leucite* disseminated through it; that of Mt. Loa is mostly of the first four of the kinds just mentioned. But about some parts, and even at the summit, of Mt. Loa, there are *clinkstone* and *porphyry*,—compact light-colored *feldspathic* rocks *without cellules*. It is not an uncommon fact that, while the ordinary rocks of the exterior of a volcanic mountain are the heavy cellular dolerites and basalt, those of the interior (as best seen when the mountain-mass is intersected by profound gorges) are of these compact feldspathic kinds having no resemblance to ordinary lavas.

2. **Liquidity of lava.**—The liquid lava flows usually with nearly the mobility of melted iron or glass. The whole of the flowing mass does not, however, appear to be properly in a liquid or melted condition; a portion, in *unfused* grains, is suspended in a fused portion. As the heat just below the surface has the intensity of what is called white heat, any part of the rock-material which is fusible at this temperature, or, rather, which is not consolidated at this temperature (for the material has come from the depths below, where the heat is much greater, it increasing with the depth or pressure), will be in a melted state. In the crater of Kilauea, the liquid lava cools at surface into a scoriaceous glass, and this glass was, beyond doubt, in fusion, like the glass of a glass-furnace,—though perhaps less perfectly, as stony unfused grains may be disseminated through it. Below the surface, six inches more or less, the lava has the aspect of a cellular rock; but even glass takes this form if very slowly cooled, and would do so all the more readily if it contained a large amount of unmelted grains of any stony material.

At Kilauea the liquidity is so complete that jets, but a quarter of an inch through, are sometimes tossed up from a tiny vent, and as they fall back on one another make a column of hardened tears of lava. Again, the winds draw out the glass of the lava-jets in the boiling pools into fine threads, by carrying off small fragments, and thus make what is called *Pélé's hair*, the crater being the residence, in native mythology, of the goddess Pélé.

The mobility is also very largely promoted by the vapors rising in the lava, especially the overheated steam. This is considered its sole cause by Scrope.

3. **Vapors or gases.**—Besides *air*, *steam* (vapor of water), and *sulphurous vapors* (either sulphurous acid or sulphur), there are sometimes (1) *Carbonic acid gas*, derived from limestone, and perhaps from other sources below; (2) *Muriatic acid gas*, derived from sea-water, but probably not exclusively.

But these two gases, along with nitrogen and sulphuretted hydrogen, are mostly emanations from *fumaroles*,—vents of hot air, steam, or sulphurous fumes, in the neighborhood of a volcano,—rather than from the liquid lava. Further examinations of the gases which escape from the liquid lavas in the crater are

required. About Vesuvius and many other volcanoes incrustations of common salt and other chlorids form during an eruption in places a little distant from the scenes of intensest action; and these, as well as the muriatic acid, appear to show that sea-water gains access to the lavas; and, if so, fresh waters also may. The steam may come partly from the depths of the lava, and partly from superficial waters.

2. Volcanic Phenomena.

1. **Rising and projectile effects of escaping vapors.**—The water and other vaporizable substances within the lava are under a pressure of about 125 pounds to a square inch for every 100 feet of depth. Owing to the heat and their consequent expansion, they slowly rise in the heavy, viscid liquid; as they rise, they keep expanding, until, nearing the surface, they begin to take the form of vapors, and finally break through.

The bubble or vapor in boiling water has projectile force enough, as it breaks at the surface, to throw up water in jets to a height of two or three inches. Were the resistance greater, as in a more dense and viscid liquid, the bubbles would become larger by additions before they could escape; the force would therefore be greater and the jets higher. In lavas which have the freest liquidity, as those of Kilauea, the jets are thirty to forty feet high. Consequently, a surface of liquid lava, as in the lakes of lava in Kilauea, is covered throughout with jets, like a vat of boiling water, and there is only a muttering noise from the action. It looks like ordinary ebullition, only the jets are jets of fiery liquid rock. They rise vertically, and fall back into the pool, or on its sides, before they have cooled. A lake 1000 feet in diameter (at *a*, fig. 969) was there in brilliant play over its whole surface when visited by the author in 1840; and, in more active times, a large part of the area of four square miles has been in this boiling state.

If the lavas be less liquid, the vapors are kept from escaping, by the resistance, until they have collected in far larger bubbles, and, when such bubbles burst, the projectile force may be enormous; it carries the fragments far aloft, to descend in a shower of cinders of great extent.

Such bubbles, rising and bursting, were seen by Spallanzani in the crater of Stromboli, a high cinder-cone in the Mediterranean, north of Sicily. In times of moderate action at Vesuvius, the outbursts of cinders occur every three to ten minutes; but in a period of eruption they are almost incessant. According to Sir Wm. Hamilton, the cinders rose to a height of 10,000 feet at the eruption of 1779,—a height indicating a vast projectile force. Occasionally masses of lava are thrown up which descend like huge cannon-balls, having been rounded by the rotation before they had cooled, and rendered compact exter-

nally, while usually cellular within. Such masses are called *volcanic bombs*. They may have lenticular as well as spheroidal shapes.

2. **Movements of the lavas in the crater.**—(*a.*) *Upward movement.*—As the vaporizable substances (water, sulphur, etc.) and atmospheric air expand while rising in the volcanic vent, they displace correspondingly the lava, and so cause a general expansion of the mass. This alone produces a rise of the lavas in the conduit.

When the boiling of a viscid fluid in a tube causes its upper surface to ascend, because the liquid at top becomes inflated or frothy with vapor, it exemplifies the same principle, although the degree of inflation very far exceeds that in a dense lava. The fact of a rising in the volcano from this cause is beyond question.

This rising becomes apparent in overflowings from the pools of the crater, over its bottom, in streams which cool and become solid lava. Whether the whole rising is due to this cause is not ascertained. The risings and overflowings are repeated from time to time, until the material within the crater has reached a height and an intensity of action that lead to an eruption.

At Kilauea (the bottom of which, when at its lowest mark, is 3000 feet above the sea) the conduit of liquid lava descending downward below the crater is 3000 feet long to the sea-level; and it may extend many miles, or perhaps scores of miles, below this. Nineteen miles would correspond to about 100,000 feet. A rise of the lavas within the crater of 400 to 500 feet in the manner above explained is all that in three cases of eruption at Kilauea preceded the outbreak. Five hundred feet in 100,000 is an average expansion of only a half of one per cent. But it is probable that the vapors which produce this result are comparatively superficial; they may be from the fresh or salt waters of the surrounding region.

The increase of activity as the lavas rise in a crater has two obvious causes: (1) the temperature of the lavas increases with the pressure; and, consequently, a rise of 100 feet would have increased very much the temperature at the bottom of that 100 feet, and so on for greater depths; (2) the rise exposes a higher column of liquid lava above to the action of external waters.

(*b.*) *Circulating movement.*—In the lava-conduit the greatest heat is along the centre, most remote from the cold sides. Hence, as in any cauldron, the ascent from inflation by rising vapors would be greatest at the centre; there would therefore be at the surface a flow from the centre to the sides, and a system of circulation. This was exhibited on a grand scale at Kilauea in 1840, where the liquid lava in the great lake (1000 feet across, *a*, fig. 969) seemed like a river that came to the surface for a moment and then disappeared.

The area of greatest heat was near the northeast side of the lake, and the stream seemed to flow to the southwest.

3. **Eruptions.**—(*a.*) *General facts.*—The rising of the lavas within the crater, and the activity of the vapors from one cause or another, reach such a height and have so great power that an eruption takes place,—either over the brim of the crater, or through the fractured mountain. The lavas flow off to a distance sometimes of sixty miles or more. Examples are given beyond.

The outflow of lavas is attended in most volcanoes, as in Vesuvius, with the ejection of cinders, and they continue to be thrown out long after the flow has ceased. They thus build up a cinder-cone immediately around the open vent.

Most of the small cones about volcanic mountains—called often *parasitic cones*—are formed in this manner about a point in some opened fissure from which lavas were ejected. Cinder and vapor eruptions are the last effects of the subsiding fires of a volcano. Mt. Kea is an example of a mountain-cone finishing its career as an eruptive volcano by the formation of a number of cinder-cones at summit: their height is 300 to 500 feet. In other cases, the central vent continues to eject cinders for a long period, and the mountain becomes high and steep.

Where the liquid rock flows from an open vent or pool, like those of Kilauea, the lava has a surface-crust, four to six inches thick, of glassy scoria, which is light and rather fragile. Boiling covers the lavas in the pools with a scum, as it does molasses, and the scoria is the hardened scum or froth. Below this scoriaceous surface the lava is solid rock, often containing only a few ragged cellules.

When the outflow takes place from fissures through which the lavas come up without having undergone any boiling, the stream is often solid lava throughout, without any scoria; the surface is hard and compact, but looks ropy, owing to the marks of flowing.

Whenever the stream of lava stops on its course, it rapidly hardens over its surface; if it is then made to move again from another accession of lavas, the hardened crust breaks up like ice on a pond, but makes black and rough cakes and blocks 100 to 10,000 cubic feet in size, which lie piled together over acres or square miles. Such masses are sometimes called *clinkers*. A large part of the island of Hawaii is covered by the bare lava-streams,—some with twisted ropy markings over the surface, drawn out as the sluggish liquid flowed along; others, extensive *clinker-fields*, horrid exhibitions of utter desolation.

The streams of lava over the land often rise into great protuberances, many yards across, with oven-shaped cavities within, formed by waters beneath that were evaporated by the heat while the flow was in progress.

In a submarine eruption, or wherever the lavas enter the sea, an upper portion of the outflow, in contact with the water, is shivered to fragments; if in deep water, the fragments are deposited, and make a stratum of tufa, sometimes taking a conical form; if at the water's edge, they rise in a shower of water and cinders, and fall around, making a tufa-cone, besides spreading far and wide over the adjoining region; or they make a permanent boiling basin, which

also is the centre of a tufa-cone. This latter kind of tufa-cone has a saucer-shaped crater and the inward and outward slope of the layers represented in fig. 971; while the preceding may fail mostly of the inward slope.

(*b.*) *Forces causing eruptions of lava.*—The forces causing eruption are as follow:—

A. Hydrostatic pressure in the lavas against the sides of the mountain. An increase of 500 feet in the depth of the lavas is an increase of 625 lbs. of pressure to the square inch. Such a pressure tends to produce fractures for the escape of the lavas.

B. Pressure of vapors. Vapors rising out of the lavas into any confined space may bring pressure to bear against the sides of the mountain, and, if suddenly evolved, the effect may cause fracture.

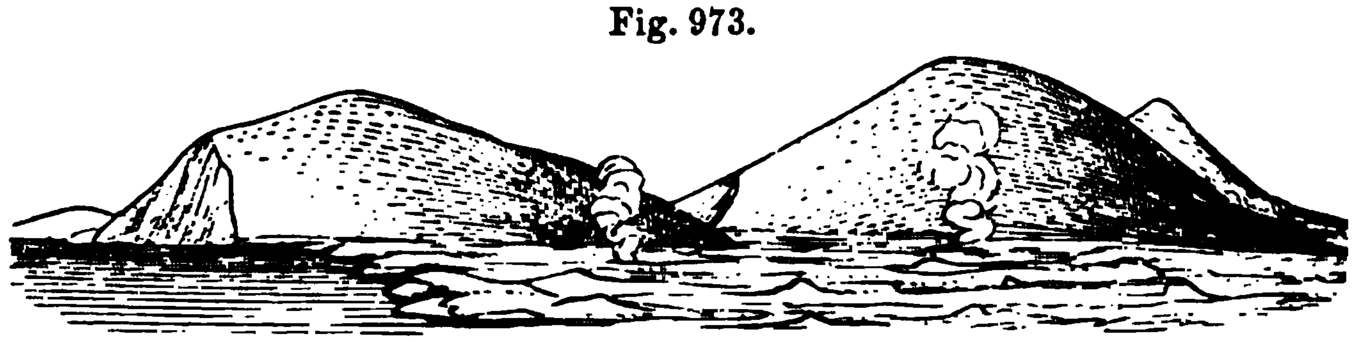
Water may come in contact with hot lavas and enter the *spheroidal* state (the state in which a drop of water is when it dances about on a red-hot stove), and, when so, it will suddenly and explosively pass into a state of vapor on cooling. This is one cause of explosion in steam-boilers; and with the apparatus of a volcanic mountain the results may rend the mountain.

C. Pressure from the slow contraction from cooling going on in the earth's crust, producing in some regions a subsidence of the crust and a pressure upward of the liquid rock in or beneath it. Contraction may also have the *reverse* effect; that is, it may make internal cavities in the crust, which may receive such liquids and draw off the lavas from open vents. It is uncertain whether the cause acts in either way.

The action of pressure alone is quiet; of vapors gradually evolved, quiet; of vapors suddenly evolved, either directly or through the spheroidal state, violent, with earthquakes.

Three eruptions of Kilauea were consequent upon the rise of the lavas to a height of 400 or 500 feet in the crater, and were attended with no violence.

Fig. 973.



Tufa-hills, Nanawale.

When ready for eruption, there was active ebullition in most parts of the immense crater, and occasional detonations were heard, but there was no subterranean shaking.

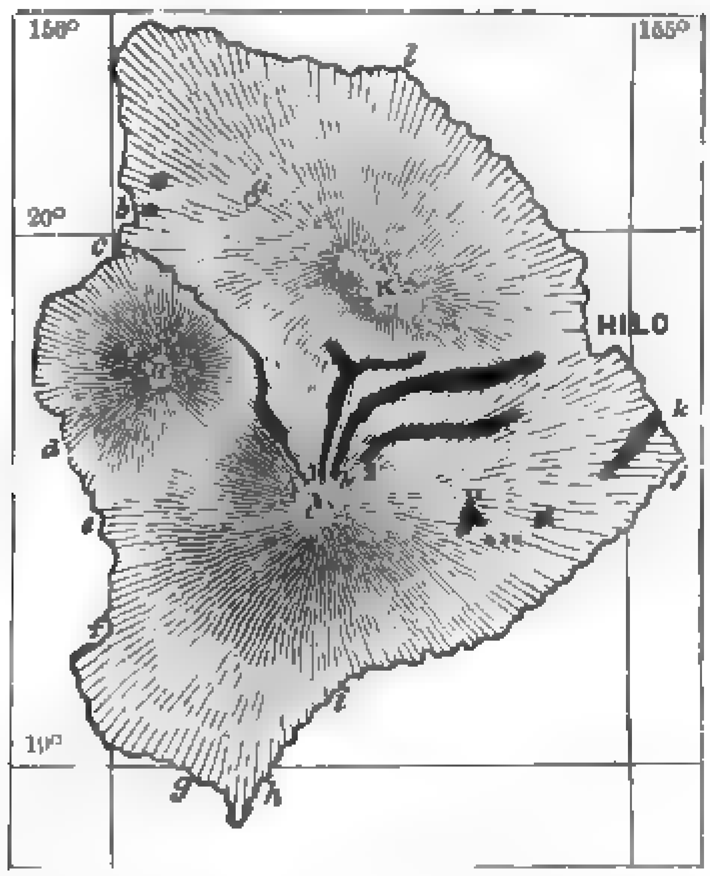
The eruption in 1840 was without earthquake; and the first sign of the out-

break was a fire in the woods. The lava broke out through a rent in the sides of the mountain, about six miles from Kilauea, and appeared for a short distance at the surface (*A, B, C*, fig. 968); then for seven miles there were a few little patches of lava, and some steaming fissures. Finally, 27 miles from Kilauea, 12 from the sea, and 1250 feet above tide-level, an outflow began from fissures and continued on to the sea at Nanawale; and three tufa-cones (fig. 973) were thrown up over these fissures on the sea-shore. It was a tapping of the mountain and letting out of the lavas; and cotemporaneously they fell 400 feet within the crater,—to *p p′*, fig. 970, which plain then became the bottom of the lower pit.

The same quiet has attended the eruptions of the summit-crater of Mount Loa. The courses of some eruptions are shown on the following map.

In January, 1843, an outflow began through fissures 13,000 feet above the

Fig. 974.



Island of Hawaii.—L, Mt. Loa, K, Mt. Kea, H, Mt. Hualalai; P, Kilauea or Lua-Pélé; 1, Eruption of 1843; 2, of 1852; 3, of 1855. 4, of 1859, *a*, Waimea; *b*, Kawaihae; *c*, Waimanalii; *d*, Kailua; *e*, Kealakekua; *f*, Kaulanamauna; *g*, Kailiki, *h*, Waiohinu; *i*, Honuapo; *j*, Kapoho, *k*, Nanawale; *l* Waipio. The courses of the currents 1, 2, 3 are from a manuscript map by T. Coan, and 4, from one by A. F. Judd.

sea (No. 1, fig. 974), and continued on northward and westward for 25 or 30 miles. It broke out in silence, though one of the grandest eruptions on record, and progressed without an earthquake.

In February, 1852, a bright light at the summit announced another eruption

(No. 2, fig. 974); after three days it was continued by means of a second outbreak, 4000 feet lower, or 10,000 above the sea, which also was a quiet one. At this second opening, as described by T. Coan, there was a fountain of fiery lavas, 1000 feet broad, playing to a height at times of 700 feet, with indescribable grandeur and brilliancy. There were rumbling and muttering from the plunging flood, and explosions, but no earthquakes. Mr. Coan attributed the fountain to the hydrostatic pressure of the column of lava above.

In August, 1855, another great eruption began (No. 3, fig. 974), without noise or shakings, at an elevation of 12,000 feet, and for a year and a half the flood continued: the whole length of the stream was sixty miles.

In January, 1859, there was still another eruption (No. 4, fig. 974). It made its first appearance near the summit, in the same quiet manner as the preceding, Kilauea remaining undisturbed. About 1500 feet above the sea, on the northwest side of the mountain, there was a larger opening, where the lavas were thrown up, "like the waters of a geyser," to a great height. The stream here became wider, subdivided into three or more lines, and continued on towards the base of Mount Hualalai; from this point it bent northward, and then northwestward again, and finally entered the sea on the western coast, after a course of over fifty miles.

There were thus three great eruptions from the summit, with intervals of only three years and a half, and four within sixteen years.

In the eruptions of Kilauea—one of the largest of volcanic craters—there is evidence only of the action of hydrostatic pressure and of vapors quietly evolved, as the causes of the outbreak. The fountain had a head of lavas 3000 to 4000 feet high; and 3000 feet of lavas correspond to 3750 pounds of pressure to the square inch. In the eruptions from the summit-crater of Mount Loa the fountain-head is 10,000 to 13,000 feet above the sea; and the eruptions were hardly less exclusively a result of hydrostatic pressure.

In the eruptions of Vesuvius, there are usually earthquakes of more or less power, lofty ejections of cinders and dark vapors, a breaking of the mountain's summit on one side or the other, or fissures opened in the sides below. In these violent ejections there may be proof of a sudden evolution of vapors. But pressure also acts as at Mount Loa; for the volcano, during the year or more preceding, has become charged nearly to its brim, ready for the outbreak.

(c.) *Eruptions mostly through fissures.*—Most eruptions take place through fissures in the sides of the mountain, and not by overflows of the craters. The fissures may come to the surface only at intervals, so as to appear like an interrupted series of rents, although continuous deep below; and they may underlie the erupted lavas as far as the flow extends, although nothing appears to indicate it, owing to their being concealed from view by the lavas. But frequently small cones form over the wider parts of the rent, and stand along the lava-field, marking the courses of the fissures.

This method of eruption through fissures makes dikes (p. 122) in the mountain; and all volcanic mountains, when the interior is exposed by gorges, contain dikes in great numbers. After the

mending of the fracture by a filling of solid lava, the mountain is stronger than before.

(*d.*) *Eruptions periodical.*—Three eruptions occurred at Kilauea at intervals of eight to nine years, this being the length of time required to fill the crater up to the point of outbreak, or four to five hundred feet. The action was regular in its period, or a result of a systematic series of changes, and not paroxysmal. The crater filled up again in eight years after 1840. But, for some reason, the fires then began to decline (perhaps after a submarine eruption), and another eruption has not taken place.

Even in the case of Vesuvius—the other type of volcanoes—the history may be similarly progressive, although the violent activity excited usually ends in a kind of paroxysmal eruption. There are, however, so many causes of irregularity that the periodicity, if existing, would be distinguishable only after a long period of observation.

(*e.*) *Difference in eruptions due to liquidity of lavas.*—At Mount Loa, the absence of cinders and the low lava-jets prove remarkable liquidity in the lavas at all times. At Vesuvius the great abundance of cinder-eruptions proves equally the viscidity of the lavas. In the latter case, the escape of vapors would be more likely to be repressed until violent paroxysmal effects became a consequence of the accumulation; and this may be one reason of the earthquakes attending the eruptions of such volcanoes.

4. Origin of the forms of volcanic cones.

The general form of the growing mountain has been stated to depend on the nature of the material ejected, whether lava, tufa, or cinders, or combinations of these. But there are modifications arising from other causes. The principal one is the following:—

The angle of declivity in a growing cone depends on the part of the cone from which the eruptions take place. Overflows at top, if descending but part of the way to the base, increase the height and steepness; but descending all the way to the base they add to the magnitude of the cone without varying the general slope. In fissure-eruptions, fissures at the summit widen the top and increase the slope, for it is like driving in a wedge; but fissures and outflow about the base spread the base and diminish the average slope: the southeastern slope of Mount Loa spreads out for a score of miles at an angle of one to three degrees, owing to this flattening process. The slope, then, of a cone depends on the concomitant action of the force causing eruption (this force

fracturing the cone, and sometimes increasing, sometimes diminishing, its slope), and the ejection of lava or other material over the sides.

The slope of flowing lava, while generally small and producing cones of small angle, may still be of almost any angle. It forms continuous streams of 30°, and even vertical cascades of solid lava occur about Mount Loa and other volcanoes. As Prevost observed, flowing lava, like flowing beeswax, if stream follows stream rather rapidly, and not too copiously, so that one becomes melted to another, may make layers of great thickness having a large angle of inclination. Hence, while the average angle of a lava-cone is small, because lavas when in a very large outflow spread rapidly and easily, there are many regions of much steeper angle over its declivities. The author observed a stream descending into the crater of Kilauea at an angle of 30°. It was, however, hollow, the interior having run out after the crust had formed. Mr. Coan mentions the frequent occurrence of slopes of 15°, 20°, and 40° along the stream formed at the eruption of Mount Loa in 1855.

The outflow of lavas from a vent is an undermining process, and the region about the crater sometimes subsides as a consequence of it. There are many fractures and a large depressed border around Kilauea produced by this means.

The violence attending eruptions at times opens widely the mountain and makes deep gorges that become filled by lavas. Maui, one of the Sandwich Islands, has a volcanic mountain 10,000 feet high, a crater like Kilauea, at summit, 2000 feet deep, and two deep valleys with precipitous sides leading down to the coast, one northward and the other eastward, where the lavas flowed off at the last eruption. It seems as if a quarter of the island had been started from its foundations. Oahu consists of parts of two volcanic mountains. The one of them which is most entire is only a remnant of the old cone,—about one-third: a precipice twenty miles long and one to two thousand feet high, the course of a great fracture, is a grand feature of northern Oahu. As there are small cones over the very region where the large part of the cone has 'sunk, the fracture must have occurred before the volcano was extinct.

Mount Somma is part of an outer wall to Vesuvius; and it is supposed, with good reason, that the fracture of the mountain at an eruption reduced the mountain to its present size.

The Val del Bove is a famous gorge or valley, with precipitous sides, 1000 to 3000 feet high, in the upper slopes of Mount Etna. Fresh-looking lavas cover the bottom, and dikes intersect the sides. It has been regarded as the result of subsidence. It is altogether probable, as suggested by the author in his Report on Volcanoes, that at its head it was once a crater, like Kilauea or the summit-crater of Maui. The conditions within and about the great depression accord with this view.

5. Subordinate volcanic phenomena.

1. **Solfataras.**—Solfataras are areas where sulphur-vapors escape and sulphur-incrustations form. They occur away from intense volcanic action. Incrustations of alum are common in such

places, arising from the action of sulphuric acid on the alumina and alkali of the lavas. A decomposition of the lavas is another consequence, producing *gypsum* (or *sulphate of lime*) through the action of the sulphuric acid on the lime of the feldspar or pyroxene, and also setting the silica free to make incrustations in the form of opal or quartz, or siliceous earth. Carbonic acid is sometimes given out in such places, where there is limestone below to be decomposed,—an acid (either sulphuric acid or silica in solution) setting free the carbonic acid by combining with the lime.

2. **Hot springs.**—Hot springs are common in volcanic regions. The waters may be pure, or of a mineral character. In Tuscany they give out boracic acid. In Iceland they are large and move in intermittent jets, and are called *Geysers.* The tossing of the water, which is in some cases to a height of 200 feet, is supposed to be owing to a sudden production of steam in chambers beneath. The stream, like any other subterranean stream, may have its head in the mountains. But it comes in contact with the hot rocks, and the heat and geyser-movement is the consequence. It has been suggested that the waters are temporarily in the spheroidal state from contact with the lavas below; and as they increase by additions, after an interval, they suddenly fall below the temperature requisite for this state, and then the explosion or jet takes place.

The waters decompose the lavas, and take up the silica, owing to the heat, and the presence of a little alkali derived from the feldspar of the lavas. This silica is deposited around the sides of the vents, forming a neat bowl-like crater with low sides, and covering a large region in the vicinity with siliceous depositions, besides petrifying wood. There is a large geyser-region in New Zealand, and another in California on the border of the desert. At the latter boracic acid is given out, as at the Tuscan lagoons.

When the ejection is in a muddy area, as in California, it forms mud-cones.

6. Source of volcanoes.

The internal fluidity of the globe, or of great regions beneath the outer crust, being proved, volcanoes are naturally regarded as outlets to the surface of the interior fluid. They mark the points where the vaporizable materials of the interior, which naturally work upward, rise through the hardened crust with the lavas they inflate. Prevost uses the homely comparison of a molasses-cask in which the fermenting molasses is working out at the bung-hole,—noting only this difference: that the vapor which does the work has another source than fermentation. The occurrence of volca-

noes along great lines of mountains, and in linear series, as if over profound fractures, are facts sustaining this view of their source.

The necessities of any single volcano, like Etna, or a single cluster of them, like those of Hawaii, might be met by a separate lake of fire beneath. But when an ocean like the Pacific is girted by volcanoes, and also blotched all over with the results of volcanic fires, such a hemisphere of volcanic action needs a vast sea of fire beneath, if not a hemisphere of igneous action. A volcano is ever discharging heat into the air by its lavas and gases, and must have some deep source below.

Supposing the interior of the globe to be fluid, and this to be the primary source of volcanic action, it does not follow that a connection with the interior is retained by every active volcano. After beginning on a fracture reaching through the crust, it may have become cut off by cooling, so as afterwards to extend only to a reservoir of liquid rock; when several volcanoes have been opened on a single profound fracture, they may afterwards have become wholly disconnected from one another as well as from the earth's interior. Known facts about volcanoes do not settle this question, though favoring the idea of disconnection. Kilauea, on the flanks of Mount Loa, is one of the largest volcanic craters on the globe; and yet eruptions occur at the summit of the same mountain, 10,000 feet above the level of Kilauea, and so extensive that the lavas flow off for 25 to 50 miles without any sign of sympathy in the lower crater. If the two are connected, the siphon has the liquid 10,000 feet higher in one leg than in the other.

This connection is possible only on two suppositions:—(1) that it is at such a depth that 10,000 feet is but a small fraction of the whole length, and the additional pressure is more than counterbalanced by the friction along the conduits; or (2) that, if the lavas rise in consequence of an inflating process, the difference of length may not imply a corresponding difference of pressure.

Even about Kilauea itself eruptions sometimes take place through the upper walls of the crater to the surface (as at *P*, fig. 968), when the lavas are boiling freely in the bottom of the crater, undisturbed by the ejection.

While the linear arrangement of the volcanic mountains of a group is evidence that they all originated in one grand breaking of the earth's crust, the several volcanoes in a line may not stand over one prolonged fracture, but over a series having a common direction, in the manner illustrated by the figures on page 19. This was beyond question the mode of origin of the Hawaian Islands.

The islands of Oahu and Maui (see fig. 24, p. 31) consist each of two great

volcanic mountains united at base, and Hawaii, of three mountains. In the case of both Oahu and Maui, the *northwestern* of the two volcanoes became extinct long before the *southeastern*,—as is apparent in the profound valleys of denudation that intersect its slopes and almost obliterate its original features, while the lavas and parasitic cones of the latter look fresh and recent. In Hawaii, also, Mount Kea, the northern volcano, is the extinct one. Again, in the whole Hawaian group the only active volcanoes are in the *southeastern* island, Hawaii, while the *northwestern* island, Kauai, shows in its features that its extinction was among the earliest, if not the very earliest, of the whole number. It appears, therefore, that each, Oahu and Maui, stands over a fissure which was *largest towards the southeast*, since the fires of the southeast extremity of each were last extinguished; that Hawaii had a similar origin, but with probably a second more western fissure as the origin of the volcano of Hualalai; and that the whole Hawaian group originated in a series of fractures which increased in extent from the northwest to the southeast; for Maui continued in eruption long after Oahu (a more western island in the group), and Hawaii, the southeasternmost, is the only island now active, and the one that through its prolonged activity has attained the greatest height above the sea.

These facts illustrate a general principle with regard to the fractures of the earth's crust, as well as the origin of volcanic groups.

2. IGNEOUS ERUPTIONS NOT VOLCANIC.

Non-volcanic igneous eruptions are those that take place through fissures in regions remote from volcanoes. The cooled rock occupying the fissure is called a *dike*. Some of the characteristics of non-volcanic rocks and dikes are mentioned on pages 117 and 122.

These eruptions have occurred on various parts of all the continents, but especially along their mountainous or hilly border-regions. Examples in New England and along other portions of the Atlantic border of North America have been mentioned (p. 430), and others in the Lake Superior region (p. 195). But over the larger part of the Mississippi basin they are wanting. They abound in many parts of Europe, and are very numerous in western Great Britain, especially in Cornwall, Wales, and portions of Scotland, as well as in Ireland. Fingal's Cave and the Giants' Causeway are noted examples. They may be not less abundant in eastern England, beneath the covering of Mesozoic and Cenozoic formations which there prevail.

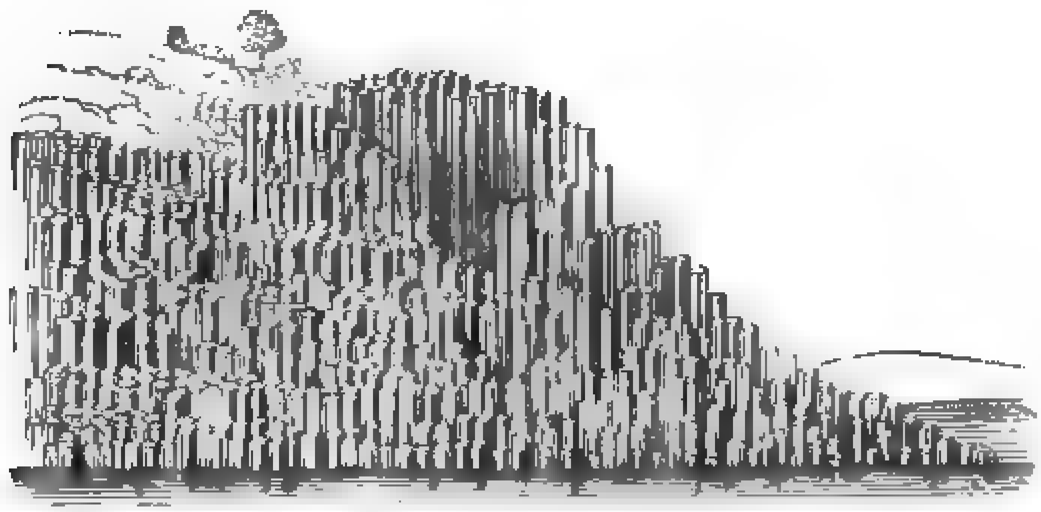
The columnar form which the rocks often assume—not unknown even in volcanic regions—is well illustrated in the accompanying sketch (fig. 975) of a scene in New South Wales.

The dikes differ in width from a fraction of a foot to several yards or even rods.

The rocks include nearly all the igneous rocks mentioned on

pages 86–89, except the scoriaceous and glassy kinds. Dolerite, basalt, diorite, and porphyry are the most common. They are often cellular, owing to inflations by steam or other vapors; but the cellules have generally a smooth or even surface within, and are not ragged like those of lavas,—a fact due to their having been under pressure when formed. When cellular, the rocks are said to be *amygdaloidal*, and are often called *amygdaloids*,—the cavities being

Fig. 975.



Basaltic columns, coast of Illawana, New South Wales.

occupied usually by zeolites in nodules which are sometimes almond-shaped.

The fissures were formed by a fracturing of the earth's crust down to some region of liquid rock, if not to the earth's liquid interior. They have thus the same origin as volcanoes,—but with this difference: that the fissures were not so large as to remain open vents.

In many cases these fissures have been made through the subsidence of an area of depression, which was continued until the increasing tension on the lower side of this inverted and subsiding arch of rock finally caused fractures opening from below upwards, that gave exit to the liquid rock. The origin of the dikes in the Connecticut River valley and of those in the Lake Superior region has been thus explained on pages 432 and 195.

The great numbers and very wide distribution of such dikes over the globe, taken in connection with the distribution of volcanoes, and regions of metamorphism, leave little room for doubt that the interior of the earth is in a liquid state, notwithstanding the results of some mathematical calculations.

3. METAMORPHISM.

1. General characteristics.

The process of metamorphism is simply a process of change or alteration, such as has occurred among many of the strata of the globe after their original deposition. The term is applied especially when the changes have affected great series of strata, producing, as an extreme result, a crystallization of the rocks, and, as a more moderate effect, simple consolidation, and where it is evident that some degree of heat above the ordinary atmospheric temperature has been concerned.

Cases of local alteration of structure and crystallization are common, modifying the composition of isolated crystals or masses. But such changes come mostly under the term *pseudomorphism* (from ψευδής, *false*, and μορφή, *form*). If, however, as is not unusual, they occur over considerable areas, or near dikes or veins, and are not due simply to ordinary mineral solutions infiltrating through a rock or seam, or to some similar local action, but to a wider cause analogous to that crystallizing the metamorphic rocks and requiring some elevation of temperature, they are then examples of true metamorphism. Still, it is often difficult to draw the line between the two series.

Examples of metamorphic rocks in part fossiliferous are mentioned on pages 270, 391, 392. The famous Carrara marble is an altered Jurassic limestone underlaid by talcose and mica schist and gneiss. The crystalline rocks of the Alps are largely of the same age: according to Charpentier, Lardy, and Studer, Belemnites occur near St. Gothard in a micaceous schist containing garnet; and in the Grisons, Murchison observed a *nummulitic* rock turned into a kind of gneiss. Crystallized limestones in the Urals still retain in places their Palæozoic fossils. In the Vosges, corals are said to occur in a hornblendic rock changed, without a change of form, to hornblende, garnet, and axinite.

The various *kinds of metamorphic rocks* have been described on pages 74–84; and examples of the *results* on a large scale have been presented at length in the case of rocks of the Azoic age on pages 138–142, and of those of the Palæozoic ages on pages 409, 410. The pages referred to are a proper introduction to the review of the subject and the additional explanations which are here given.

2. Effects of metamorphism.

The principal effects of metamorphism upon rocks are the following:—(1) Consolidation; (2) Loss of water or other vaporizable ingredients: (3) Change of color; (4) Obliteration of fossils; (5) Crystallization, with or without a change of constitution.

1. *Consolidation.*—Ordinary atmospheric or subterranean waters, however prolonged their action, do not necessarily produce solidifi-

cation. The soft sandstones of all ages, from the Potsdam to the incoherent beds of the Post-tertiary, are evidence on this point. It is probable that deposits to an immense extent have existed in past time that failed to be consolidated, and were consequently washed away in the course of subsequent changes.

But, while there are many fragile Potsdam sandstones, there are others, as those of eastern New York and Vermont, that have been hardened through the metamorphic process into quartzites or granular quartz rocks; and deposits of sand and pebbles of various other ages that are refractory sandstones and grits. That the consolidation took place through the metamorphic process, is often evident from their position within, or on the outskirts of, regions of other metamorphic rocks. In the same way, fragile absorbent argillaceous shales have been hardened into firm non-absorbent slates.

The common modes of consolidation not here included among metamorphic processes (although the term in its widest meaning might comprehend them) are the following:—

(*a.*) Carbonate of lime, derived from granulated shells or limestone, is often disseminated through arenaceous beds, and, when so, infiltrating waters may take into solution and deposit again some of the carbonate, and thus cement the sands. Blocks from a soft calcareous sandstone often increase in hardness after being removed from a quarry and put into a structure where they are exposed, over the surface at least, to alternate drying and moistening through atmospheric causes.

(*b.*) Beds of sand often contain disseminated grains of some ore of iron, which are altered by infiltrating waters, and which afterwards become solid and thus solidify the mass. The decomposition of iron pyrites, and the peroxydation of its iron, and of that in carbonate of iron and magnetic-iron ore, are the common methods. The result is often a rock stained, or wholly colored, *red* or *brownish-yellow*,—the former color when the process goes on out of water where the atmosphere has free access. The ferruginous material may also be derived from external sources.

2. *Loss of water or other vaporizable ingredients.*—The *water* contained in the original material of a rock is sometimes wholly, and sometimes but partly, expelled. Serpentine is a metamorphic rock containing 12 per cent. of water; and talcose slate contains 5 or 6 per cent. In many others more crystalline, water is essentially absent. The *bitumen* of bituminous coal has been partly or wholly driven off by the process, and anthracite and semi-bituminous coal formed (p. 410).

Carbonic acid is expelled from carbonate of lime, or limestone, as is well known, in a heated lime-kiln. But in the metamorphism of limestone it is retained. It has been shown by experiment that

the carbonic acid is not given out if the material is under heavy pressure. If this be true of carbonic acid, it will be so also of other ingredients less easily expelled.

3. *Change of color.*—Compact limestones are usually of grayish, yellowish, brownish, and blackish colors. From the metamorphic process they often come out white. The original color in these and argillaceous beds is often due to carbon from ancient plants or animal matters; and, when so, this carbon is removed and the rock blanched,—just as the limestone in a lime-kiln turns white. When oxyd of iron in any form is present, the blanching does not take place unless the oxyd is thrown into some new state of combination in the crystallizing process. When there is only a partial metamorphism, its presence generally causes a change of color to red.

4. *Obliteration of fossils.*—Rocks that have been subjected to the metamorphic process have usually lost all their original fossils. Where the metamorphism is partial, the fossils may in part remain, only obscured. The Devonian coral limestone of Lake Memphremagog contains some nearly perfect corals; but most of them are much flattened and indefinite in outline, and others are only patches of white crystalline carbonate of lime in a bluish-gray limestone rock, which is itself hardly at all crystallized. A step further in the process, and the limestone would have become a whitish rock of uniform granular texture, with no traces of the fossils, except, it might be, in white veinings and blotches.

5. *Crystallization.*—The variety of crystalline rocks formed by the metamorphic process, and the wide extent of the regions over which they have been formed, will be learned from the pages already referred to in the earlier part of this volume. They occur in all parts of the world, underlying sedimentary formations, if not at the surface, and they are of various ages, from the Azoic to the Tertiary. While the Appalachian crystallization and that of New England took place before the Mesozoic era, that of the Sierra Nevada in California, according to Whitney, occurred as late as either the commencement or end of the Cretaceous period; and that of portions of the Alps, after the Jurassic or Cretaceous.

The crystallization, in some cases, involves no change of composition. This is the fact with most limestone; the ordinary compact rock may be simply changed by the process to a crystalline-granular condition, and bleached in color.

In other cases the constitution is altered, new mineral species being formed. Argillaceous shales are changed to mica schists, and argillaceous sandstones to gneiss or granite. Even in the case of limestone, the impurities are turned into crystalline minerals of

different kinds, such as *garnet*, *idocrase*, *pyroxene*, *scapolite*, *mica*, *sphene*, *chondrodite*, *apatite*, etc.

The crystallization which is produced by the process is of all grades, from mere solidification of a bed of shale or sandstone, to the formation of a perfect granite.

3. Origin of metamorphic changes.

Promoting cause.—The great promoter of metamorphic changes is *subterranean heat*, acting in conjunction with *moisture*, and usually, if not always, under pressure.

The heat requisite for metamorphism is less than that of fusion; for the evidence is decisive that although the rocks may be so far softened as to have some degree of plasticity, this is unusual, and for the most part a comparatively low temperature is all that is required. It is probable that the results have generally taken place between 300° and 1200° F.; but it was heat in slow and prolonged action, operating through a period that is long according to geological measure. A low temperature acting gradually during an indefinite age—such as Geology proves to have been required for many of the great changes in the earth's history—would produce results that could not be otherwise brought about, even by greater heat.

The lower limit of temperature is sometimes placed much below 300° F.; and for consolidation it may be rightly so. But there is definite evidence that it has exceeded this in the majority of cases. In the great faults of the Appalachians, 10,000 to 20,000 feet in extent, Lower Silurian limestones are brought up to view, containing their fossils, and not metamorphic. Taking the increase of temperature in the earth's crust at 1° F. for 60 feet of descent, 10,000 feet of depth would give 220° F. as the temperature of the limestone before the faulting, and 20,000 feet would give 390° F. But 1° F. per 60 feet of descent is the present rate, and must be far short of that at the close of the Carboniferous age, when the earth's crust was so easily flexed and metamorphism took place on so grand a scale; and hence the limestone must have been subjected to a heat far above 220° F., if at a depth of 10,000 feet. The length of time, moreover, during which it was thus heated must have been great, as follows from the age of the rocks and the period of the faulting.

Moisture is essential, because dry rock is a non-conductor of heat (as well shown in the case of a common fire-brick), and also because of its chemical powers when heated. Rocks usually contain some moisture; and, when moist, heat is conducted readily through them.

The pressure may have been either that of superincumbent waters or of overlying rocks. A little thickness of the latter would give all the pressure that is in any case essential.

The evidence that heat has been the promoting cause is as follows:—

1. *The effects are analogous to those which heat is known to produce.*— Water, though a weak chemical agent when cold, if heated, has increased solvent and decomposing powers and increased efficiency in promoting chemical changes. When heated under pressure above the boiling-point of water (212° F.), it has the qualities, or is in the condition of, superheated steam, and is then an exceedingly powerful agent as a destroyer of cohesion and solvent, and a promoter of decompositions preparatory to recompositions, as Daubrée and others have shown. The moisture disseminated through rocks and distributed among them would be for the most part, if not everywhere, in this superheated condition.

When feldspar, or a related mineral, is acted upon by these means, the waters take its alkalies and silica and become a siliceous solution, fitted to promote solidification or to make new crystallizations; and when moisture is diffused through a rock containing feldspathic ingredients, this siliceous solution is alike diffused, and a simple cooling may cause it to concrete and solidify the mass. The Geysers afford an example of siliceous waters formed in this manner. These siliceous solutions, or, more properly, solutions of a silicate of potash or soda, are in a state to promote combinations, and, wherever the conditions are favorable, may aid in the formation anew of feldspar and other silicates.

Crystallizations of epidote, tourmaline, pyroxene, and other species have been formed in the sandstones adjoining trap dikes, through the heat which the trap had when ejected. Near Rocky Hill in New Jersey, also on the Delaware at Lambertsville, and opposite at New Hope, there occur, under these circumstances, short prisms of black tourmaline half an inch in diameter, along with epidote. The rock has been distinctly baked by the heat in some cases to a distance of a quarter of a mile, and consolidated to a much greater distance.

A trap dike intersecting the clayey layers, sandstones and coal beds of the island of Nobby, New South Wales, has baked the clayey layers to a flint-like rock to a distance of two hundred yards from the dike, the whole length of the island: the baking effect must have continued much farther,—though the direct evidence is cut off by the river.

Daubrée, besides decomposing various silicates by means of superheated steam, has made, in this way, quartz crystals, feldspar, pyroxene, and mica, the crystallization taking place *below the point of fusion.*

Through the diffusion of superheated steam at a high temperature, the rocks may have derived increased flexibility, so that a material otherwise unyielding, as limestone, was flexed under the slowly-acting pressure, without breaking. The effect may have been even greater in some cases, and have produced plasticity, or semi-fusion,

in which state limestone might have been pressed into fissures in adjoining rocks so as to make a species of injected vein. The fissures and openings in rocks formed while the metamorphism was in progress, and the distinctness in most cases of the original planes of lamination, are evidence that this plastic or semi-fused state was not common in metamorphic operations. It may have been one of the conditions requisite for the formation of granite,—a non-schistose rock; and the transitions from gneiss to granite, which are by imperceptible gradations, may indicate different degrees of this state.

There may seem to be some difficulty in accounting for metamorphic results on the ground of the diversity of mineral species that are produced. But, in the *first* place, the elements constituting these species are few in number,—silica, alumina, potash, soda, lime, magnesia and the oxyds of iron being all that are necessary for the great majority of them; in the *second* place, the material of sedimentary strata is, to a large extent, nothing but pulverized metamorphic rocks, so that the metamorphism is often only a new crystallization of the minerals already present: and, in the *third*, the organic remains, out of which many rocks have been largely made, even the arenaceous and argillaceous, have contributed a variety of ingredients, besides carbonate of lime,—the most important of which are phosphoric acid and fluorine (p. 66).

Some argillaceous beds consist largely of true clays, resulting from the decomposition of feldspar or other aluminous minerals. But generally they are made mainly of pulverized feldspar with quartz, as is proved by the presence of alkalies found by chemical analysis. When the alkalies are absent, as Hunt has stated, metamorphism cannot produce feldspar, but may fill the slate with andalusite, kyanite, or other non-alkaline species.

The following table presents a general view of the composition of the more common rock-making materials, showing their close similarity. The names mica and feldspar each include several species:—

Silica	Quartz (p. 55).
" + magnesia and water	Talc (p. 61).
" " "	Serpentine (p. 61).
" " + lime or protoxyd of iron	Pyroxene (p. 60).
" " " "	Hornblende (p. 59).
" " + alumina and protoxyd of iron	Chlorite (p. 61).
" + alumina	Andalusite (p. 58).
" "	Kyanite (p. 58).
" " + fluorine	Topaz (p. 59).
" " + oxyds of iron	Staurotide (p. 58).
" " " " + potash or magnesia.	Mica (p. 56).
" " + lime and soda	Scapolite (p. 58).
" " + lime, magnesia, iron, or manganese	Garnet (p. 57).
" " + oxyd of iron	Epidote (p. 57).

Silica + alumina and potash, soda, or lime..................Feldspar (p. 55).
" " + alkali, magnesia, and boracic acid.....Tourmaline (p. 58).

The presence of phosphoric acid from organic remains determines often the formation in metamorphic limestones, and even sometimes in granites, of crystals of *apatite* (phosphate of lime); and the presence of fluorine may promote the crystallization of *chondrodite*, *topaz*, and some other species.

Again, all heated subterranean waters would become mineral waters, and would serve to carry the material they held in solution wherever they might have access. In addition, the ocean is a mineral source as wide as the world, furnished abundantly with soda and magnesia, and in smaller proportions with many other ingredients.

2. *The attending circumstances were favorable for the escape of subterranean heat.*—The rocks during a period of metamorphism are undergoing extensive displacements and foldings, profound fracturings and faultings, as illustrated in the examples which have been described. Metamorphic rocks are always displaced and folded rocks, and never for any considerable distance horizontal. Where the foldings are most numerous and abrupt, reducing the strata to a system of parallel dips by the pressing of fold upon fold, there, as remarked by the Professors Rogers, the metamorphism is most complete. In the case of mineral coal, the bitumen is more completely expelled the greater the disturbance of the strata; and in the metamorphic region of Rhode Island the coal is changed even to graphite by the heat (p. 410).

3. *Thermal springs in metamorphic regions.*—The thermal springs of Virginia are regarded by the Professors Rogers as owing their heat to the same cause which produced the consolidation and metamorphism in the Appalachian region; and they instance as evidence the fact that the localities where they occur are generally situated over the axis of some fold in the Appalachian strata.

It appears from the above that the escape of subterranean heat took place during a prolonged epoch of profound subterranean disturbance. As the epoch slowly progressed, multiplying folds and fractures, the heat as gradually welled up from below, penetrating the moist and yielding beds,—in some regions, where the uplifting was least, only solidifying the beds; in those most disturbed, crystallizing them, and filling them with veins.

Local cases of metamorphism from hot mineral waters and dikes of igneous rocks have occurred without upturnings. But these cases, while the same in their chemistry, are no examples of the great physical conditions under which the metamorphism of the thick formations has taken place.

Herschel brought forward the argument that since there is an increase of temperature for every sixty feet of descent in the earth's crust, if strata should accumulate over a region in the sea to a depth of 10,000 feet, the heat would rise accordingly into the stratified mass; and, as the same temperature would exist at a depth of sixty feet as before, there would be accordingly in the lower part of the mass the same elevated temperature that existed 10,000 feet below the former surface,—this being a means of raising heat from below without disturbance, and a degree of heat that in some circumstances might be sufficient for metamorphism. But if metamorphism had actually taken place in this way we should expect to find sections showing *horizontal* or slightly-disturbed metamorphic beds, and a gradual transition through a series of such beds to an absence of metamorphism; but this has nowhere been observed. The great Appalachian faults (p. 707) are direct testimony against the theory. It is remarkable that even in the case of the Azoic rocks, formed in a period in which it is supposed the crust of the earth was thin, there are no examples of metamorphic *horizontal* beds (p. 144); they lie *folded or tilted* beneath *horizontal* Silurian strata in Canada (p. 134).

4. Metamorphism of metamorphic rocks.

Metamorphic rocks are not proof against further metamorphism. Among the Azoic rocks of northern New York (in Fowler, De Kalb, Edwards, Russel, Gouverneur, Canton, and Hermon, St. Lawrence co.) there are extensive beds of a kind of soapstone (called Rensselaerite) which has in places the cleavage of pyroxene, showing an alteration of pyroxenic and perhaps other rocks into soapstone by some magnesian process; and the serpentine of the region may be of the same period of metamorphic change. Examples of the change of crystals and rocks to soapstone or serpentine occur in the metamorphic regions of New Jersey and Pennsylvania; and they are common in other countries. Again, in the Azoic of northern New York, at Diana and other places in Lewis county, there are beds of a soft compact rock which is sometimes worked into inkstands, and resembles the agalmatolite of China; and at one locality there are crystals of nepheline altered to this agalmatolite. These cases of the metamorphism of metamorphic Azoic rocks may have taken place during the epoch of metamorphism after the Palæozoic era, when the rocks of New England were to so large an extent crystallized.

See further, on the history of this branch of science and its processes, a Memoir by Daubrée, translated from the French by T. Egleston, and published in the Smithsonian Annual Report (8vo) for 1861.

4. FORMATION OF VEINS.

1. *Veins.*—Veins occupy either fissures intersecting strata, or spaces opened between the layers of folded beds. They may result

from any movement of the rocks, however slight or from whatever cause: they abound in all disturbed and metamorphic beds. They may have great depth, extending through a series of formations, or be confined to particular strata. Where a disturbance is in progress, the different kinds of rock will necessarily be fractured differently, according to their nature. Those that are unyielding or fragile may be broken into numberless fragments, and these fragments widely displaced: so that, when the opened spaces or fissures are filled, the rock will be reticulated with irregular and *seemingly faulted* veins. The forming of veins by the opening of layers, alluded to above, occurs especially in slate-rocks; auriferous quartz veins are to a great extent of this character. The general forms and other characteristics of veins are described and illustrated on pages 119–123.

2. *Methods of filling veins.*—There are three ways of filling veins: (1) by injection from below; (2) by infiltration from above; (3) by infiltration from the enclosing rocks either side of the vein or bounding it along some portion of its course. Under the *second* and *third* methods, heat is not absolutely necessary, though generally required.

First method.—The first method—that by which trap dikes were formed—is not the common one. There are cases, like that of the Lake Superior region (p. 195), where metals or metallic ores are directly associated with injected dikes. But it is always a question, in such a case, whether the metallic ingredient was derived from the same deep igneous source with the melted rock of the dike, or whether it was received from the rocks of the deeper walls of the fissure during the progress of its injection. The vapors or mineral solutions produced at such a time often penetrate the rock adjoining the veins, sometimes to considerable distances, either diffusing ores through them or filling cracks or long fissures.

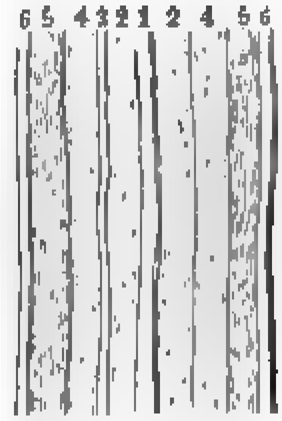
Second method.—The second method is exemplified only in superficial veins, seams, or cavities. Carbonate of lime is often thus deposited in seams or open cavities.

Third method.—The third method is that by which the great majority of the veins in metamorphic rocks, whether simply stony or metalliferous, were produced. The nature of the minerals constituting veins, their associations, and the banded structure often characterizing them, are opposed to their formation by injection. An example of the banded structure is represented in fig. 976, in which 1, 3, and 6 are sections of layers of quartz; 2, 4, of gneissoid granite; and 5, of gneiss; and other examples are described on page 123. Such an arrangement could have resulted only from a

lateral filling of the vein by slow and successive supplies of material.

The fissures occupied by veins are simply cavities penetrating the rocks more or less deeply, sometimes down to regions of great heat, but not quite to the igneous interior. During the metamorphic changes, such cavities, as soon as formed, would begin to receive mineral solutions or vapors from the rocks adjoining. The rocks could contain sufficient moisture to carry on this system of infiltration, if there were no other source, and the tendency of currents in the moisture, and any vapors present, would be towards the open spaces. The mineral matters thus carried to the fissure would there become concreted, and commence the formation of the vein.

Fig. 976.



Banded vein in gneissoid granite, Valparaiso.

These materials from the adjoining rock may be taken directly from it by simple solution, or be derived by a decomposition of some of its constituents. And, when transferred to a vein, they may be concreted unchanged, or enter into new compositions through the mutual action of the several ingredients there collected.

The veins in semi-crystalline slates are mostly of quartz, because silica is readily taken up by heated waters from siliceous minerals, and is everywhere abundant. Many are of carbonate of lime, and for a similar reason. The solutions of carbonate of lime may enter from above; but the supply has usually been derived from the materials of the adjoining rock through the process of infiltration.

The veins in granitic rocks must have been often formed at the high temperature required for the metamorphism of granite, and the material constituting them is therefore often the same essentially as that of the granite, only in a coarser state of crystallization.

In the infiltrating process, materials that are scattered very widely and only in minute quantities through the adjoining rocks are gathered gradually into these open cavities. The crystallizing of the material held in solution robs the moisture of its mineral portion, and will lead to a constant re-supply of it from the rock around as long as the material lasts or the conditions favoring its being taken up are continued. Thus veins become filled with crystals of various minerals and ores that are not visible outside of them.

The materials through every portion of a vein are not necessarily derived from the rock adjoining that portion. The granitic or

other material derived from its deeper part may rise and occupy the vein where it intersects slate-rocks.

With this mode of filling, when the process is very slow, the outer layers, or those lying against the enclosing walls, will be first formed, and then another layer inside of this, and so on, until the whole, to the centre, is occupied. By such means the banded structure is produced. Owing to the varying circumstances during the slow filling of a vein,—the work sometimes evidently of a long period,—the infiltrating material varies in kind; and hence comes the variation in the minerals constituting the successive layers, as described on page 123. Some of the layers, especially the metallic, may be formed from vapors or solutions rising from a deeper source than the range of level along which they occur.

Thus, quartz may be succeeded by fluor spar, and this by an ore of one or more metals; the last by quartz again, or by calcite; and so on in various alternations.

If the process of filling were rapid, the vein would fail of this division into layers. The adjoining rock is often cotemporaneously altered.

Certain veins in crystalline rocks which blend on either side with the rock adjoining are sometimes called *segregated veins*. They are supposed to have been formed by a segregating process, or a crystallization out of the rock in which they occur, the direction of the plane of the vein being determined, not by the previous existence of a fissure, but by magnetic currents through the rock, or other less intelligible cause. No facts authorize us to infer that magnetic currents have the power here attributed to them. Such a blending of a vein with the walls is a natural result when its formation in a fissure takes place at a high temperature during the metamorphism or crystallization of the containing rock.

3. *Alterations of veins.*—Veins do not always retain their original constitution; and those that are metalliferous are especially liable to alteration. There are often lines of small cavities through the middle of a vein or along its sides, or in both; and, when the rocks in which they occur are raised above the level of the ocean, the atmospheric waters find access as they become subterranean, and constantly trickle through them. These waters decompose some species readily (iron pyrites, etc.), and take the new ingredients (sulphate of iron, etc.) into solution. Feldspathic minerals may be decomposed, and the waters thereby become siliceous and alkaline; or, in one way or another, they may become carbonated. Thus armed, the waters go on making various changes in the ores and minerals of the vein, altering copper pyrites (sulphuret of copper and iron) to copper-glance or erubescite (sulphurets of copper), or to malachite (carbonate of copper), or changing in a similar manner ores of silver, or lead, etc. In some parts, the arrangements may

be such as to produce a galvanic effect, further promoting decompositions and recompositions. When the solutions differ, after intervals of time there will be a succession in the changes, and layers of different species may be formed.

Thus, a layer of quartz may be succeeded by one of fluor spar, or of zinc blende, or of calcite, or of quartz again, etc. In the course of the changes, a layer of cubes of fluor spar, underlying one of quartz, may be entirely dissolved away, and the cubical cavities filled up by another species, as zinc blende, etc.

The rock of the walls (especially of the lower wall, where the vein is inclined), when not united firmly to the vein, often undergoes deep alteration, and may become penetrated by ores from the vein itself, carried in by infiltrating solutions. These alterations are most extensive in the upper part of veins, where it often happens that the metals are removed by infiltrating waters, excepting for the most part the iron, which is left in the state of red oxyd, giving its color to the earthy mass at the top of the vein (called then the iron hat). Hence the occurrence of a line of red earth in the soil may be an indication of a vein of ore beneath.

Gold-bearing quartz veins generally lose the pyrites and perhaps other ores which they contain, and thus become cavernous to a considerable depth. To this distance they are mined with comparative ease; but beyond they are extremely hard and difficult to work.

4. *Veins of different ages.*—In the progress of the uplifting and folding of a region undergoing metamorphism, fissures formed at one time and filled would be liable to be broken by cross-fissures at some subsequent time in the epoch (perhaps a following day, week, or year), and these, again, by others. Thus, a succession of veins faulting one another might be formed during one epoch of disturbance, and they might differ in construction as the bands in a banded vein differ.

Again, veins may be intersected and faulted by fissures formed during subsequent epochs of disturbance.

It is evident, therefore, that a vein which faults another does not necessarily belong to a later independent epoch. When actually later in epoch, it will usually appear in the distribution of the new veins over a wide region of country, their general parallelism of direction, and their wholly distinct mineral composition.

5. *Filling of amygdaloidal cavities.*—The cavities of a lava or igneous rock (such as are formed by expanding vapors while the rock is liquid) differ from veins in size, but not essentially in the method by which they are filled with minerals. In amygdaloids, these minerals are usually chlorite, quartz, prehnite, datholite, analcime, or some of the zeolites, or calcite; and they often occur in successive layers, analogous to the layers of a banded vein. They are introduced by infiltrating waters which derive the ingredients mainly from the enclosing rock through the decomposition of some of its minerals. Quartz (glassy quartz, chalcedony, agate, carnelian, etc.) and calcite are the most common of

those minerals, just as they are in veins. Most of the species in amygdaloidal cavities are hydrous,—showing that they were formed at a much lower temperature than the materials of a granitic vein; and some of them may perhaps be formed even at the ordinary temperature. When several species occur in successive layers together, the uppermost, or latest formed, usually contain the most water in their constitution,—silica and calcite excepted, which are not hydrous species, and may occur at the top or bottom, or any part, of the series.

At Plombières in France, the cement and brick of walls of Roman origin have become penetrated in places with *zeolites* through the action of the water of a warm (140° to 160° F.) mineral spring (Daubrée).

VI. MOVEMENTS IN THE EARTH'S CRUST, AND THEIR CONSEQUENCES.

The topic under consideration in this chapter is the origin of the movements in the earth's crust or mass, and the methods by which their results have been brought about. These movements and their consequences include (1) Changes of position and level; (2) Fractures, faults, and structural peculiarities produced in rocks; (3) Earthquakes; (4) Evolution of the earth's great outlines and reliefs, and of the successive phases in geological history.

1. CHANGES OF POSITION AND LEVEL.

Changes of position may take place either horizontally or vertically, or in both directions simultaneously.

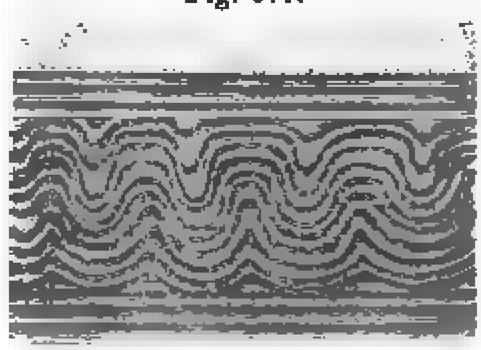
1. Causes of change.

Some causes of *local* change have already been mentioned:—

1. *The undermining of strata by the eroding action of subterranean waters* (p. 649)

2. *The weight of a superincumbent mass of horizontal deposits on wet beds of clay or sand,* producing a lateral movement, and also an extrusion if the case admits of it (p. 649).—The laminated clay-layers often become *plicated* by the pressure, while the beds between which they lie are only slightly compacted or are unaltered. Fig. 977 is a reduced view of a layer thus plicated, from the Post-tertiary of Boonville, N.Y. Vanuxem, who mentions the facts in his New York Geolo-

Fig. 977.



Plicated clayey layer.

gical Report and illustrates them with this and other figures, attributes the plications to lateral pressure while the layer was in a softer state than those contiguous. Its porous condition may have caused it to soften with water more easily than those above or below.

3. *The gravity of wet clayey or sandy beds when in an inclined position* (p. 650).—The laminated clay-layers are often *plicated* by this means, as by the preceding; and some plications in metamorphic rocks are of this origin.

4. *The undermining of strata by volcanic ejections* (p. 699).

Other causes are either *local* or *general*:—

5. *The formation, more or less sudden, of vapors within or beneath some portion of the earth's crust.*—Disturbances in volcanic regions are in part due to this cause. When in the uplifting and fracturing of the rocks by this means they become so wedged as not to fall back to their former position on the condensation or escape of the gases, a permanent elevation is occasioned.

This cause may produce effects over limited areas. It is often regarded as a prominent means of lifting mountains and continents. But mountain-chains are heavy, and continents very heavy; and such vapors, if formed, could at the most only shake the rocky crust. Mountain-chains and continents could not be sustained long on a bed of vapors. For permanent elevation, there must be some mode of holding them up after the uplift. Moreover, there is no reason to believe in the existence of the cavities beneath requisite for the spread of the vapors.

6. *Weight of accumulating formations over extended areas of the earth's surface*, producing a subsidence of the crust.—Whether this is an actual cause or not in geological dynamics, is questionable. The great subsidences of the Appalachian region have been attributed to it. But this same Appalachian region underwent oscillations upward as well as downward; and the former require a very different cause. It was finally, after long ages of preparation, the scene of disturbances and foldings for a length of 1000 miles and a breadth of some hundreds; and these effects of continental extent are not results of simple gravitation. It is probable that all the oscillations of level, and the ultimate plication of the crust over the great region, have one common cause; yet it is not impossible that gravitation may have been one cause of the subsidences.

7. *Movements in the interior fluids of the globe.*—If the interior of the earth has been through the geological ages in a state of free liquidity, there must have been tides in the molten sea which, in times of excessive height, might have caused vibrations of the crust; while if the condition was that of dense viscidity, such a result could not

have happened. In neither case could any permanent elevations of the surface, or any plications of the crust, have arisen from such a cause. The rocks show that these plications have been extremely slow in progress (p. 411), and not a result of any paroxysmal action in forces, above, within, or below the crust.

8. *Change of temperature producing expansion and contraction.*—Change of temperature may have acted in two ways:—

(*a.*) By simple expansion and contraction of some limited region within the earth's crust, as when heated from proximity to some volcanic or other igneous source of heat. The effect would be (1) a rising of the surface, with whatever might be upon it, with the expansion; (2) a sinking of the same with the subsequent contraction on cooling; (3) a lateral action or pressure on an adjoining region with the expansion (since it would tend to take place laterally as well as vertically), producing horizontal movements or displacements of small amount; (4) in some cases, on contraction, an opening of cracks or fissures, either thickly over the whole surface (as in the case of basalt and trap when divided into polygonal columns), or more distant and of greater width. The oscillations of level in the temple of Jupiter Serapis and along the adjoining coast have been explained by this method.

(*b.*) By contraction going on within the earth's interior beneath its solidified crust. The fact that this cause has acted in the earth's past is beyond question if the globe was once in a fused state, as is generally supposed by geologists. Since the crust when formed would have the size which the globe at the time had, all subsequent cooling, as it would tend to diminish the interior, would bring a slowly-increasing strain upon it, and, unable to accommodate itself to the changing size by any process of shrinkage, it must do it either by fractures or plications, or both.

The effect, in a melted spheroid, of cooling more rapidly at the surface than within, is illustrated in glass in a Prince Rupert's drop. The pressure of particle against particle over the whole exterior is so great from the interior contraction that the removal of a portion of the surface-layer by a slight scratch of a file destroys the equilibrium, and causes it to break instantly, and almost explosively, to fragments. Another familiar example of contraction beneath any exterior coat is seen in a drying apple. The exterior, in this case flexible, gradually becomes wrinkled from the diminution of size within; and the wrinkling covers the whole surface alike, unless some part be protected by resin or otherwise,—in which case the largest wrinkles would be those about the border of the protected portion.

The earth's crust has inequalities of thickness and texture distributed probably in large areas; and therefore, while conforming to the principle exemplified, it should present peculiarities in the arrangement of the effects dependent on the distribution of these diverse areas.

The cause is one in which the whole sphere has acted as a unit; and its effects must, therefore, be coextensive with its surface, but differing in different parts.

The cause, moreover, must have continued in constant action as long as cooling continued ; for cooling, however slight, implies contraction and gradually augmenting tension, and an ultimate yielding when the tension is too great to be longer resisted.

The direction in which a force of this kind acts is approximately horizontal within the crust, the contraction creating a strain or pressure between every adjoining part of it; and, wherever the crust should yield under the tension, some parts would be, as a primary effect, drawn downward, and others, as a secondary effect, pushed upward,—the latter rising through the lateral pressure or pushing action of the subsiding portion; and fracture would succeed fracture, and thus one mass rise over another, or else fold would succeed fold in parallel ranges, or both fractures and folds would take place together. The results would vary with the nature of the crust in the part raised, its condition at the time as to the presence of moisture and heat, and the kind of action in the moving power.

The natural position of the axes of the plications is at right angles to the direction of the pressure. But if the force is not uniform, and increases in one direction or the other,—a very probable condition,—the plications would show it in variations as to number, height, and position. Curves might thus result either in the axes of the plications, or in the line of maximum effect over a plicated region.

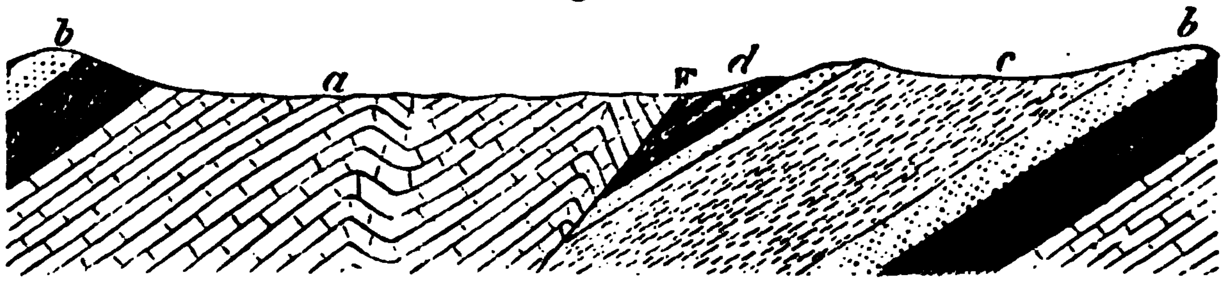
2. Examples of effects under the cause last mentioned, with additional explanations.

1. *The effects universal over the globe.*—Since the developments with regard to the structure of the Appalachians, made in the course of the geological surveys of the States of Pennsylvania and Virginia, were first published by the Professors Rogers in 1842, it has been found that nearly all inclined strata over the globe are actually portions of plicated strata; and the general principles mentioned on pages 403–407 (which should here be reviewed by the reader), although deductions from the special case of the Appalachians, are, in fact, universal principles. There is evidence everywhere that

the grander uplifts have been produced by lateral movements of the crust, and generally a pushing up of the formations into folds.

In the region of southern Virginia and northern Alabama there is a series of great Appalachian faults, and successive portions of the crust have been pushed up along sloping faults, bringing the Lower Silurian limestones to a level with beds of the Carboniferous

Fig. 978.



Section of the Palæozoic formations of the Appalachians in southern Virginia, between Walker's Mt. and the Peak Hills (near Peak Creek Valley): F, fault: *a*, Lower Silurian limestone; *b*, Upper Silurian; *c*, Devonian; *d*, Subcarboniferous, with coal beds.

age (Subcarboniferous period); and plications are a minor feature of the region. But more to the north, in middle and northern Virginia, and in Pennsylvania, there are great folds, or synclinal and anticlinal axes, with fewer great faults.

Lesley, after explaining the relations of the *eastern* or Blue Ridge, the Great Valley next west, the Appalachian or *middle* chain, and the Alleghany or *western*, and mentioning that the eastern escarpment of the last, "overlooking the Appalachian ranges with their narrow parallel interval-valleys, is the so-called Backbone Alleghany Mountain," and separates the head-waters of nearly all the Atlantic and Western rivers, observes that New River, in southern Virginia, divides the northern region of plications from the southern of great faults; and this river is remarkable for cutting through the Appalachians, and taking its rise even as far east as the Blue Ridge. He adds concerning this southern district, "The Palæozoic zone included between the Great Valley and the Backbone escarpment is occupied by as many pairs of parallel mountains as there are great parallel faults; and, as these faults range in straight lines at nearly equal distances from each other, these mountains run with remarkable uniformity side by side for a hundred or two hundred miles, and are finally cut off either by short cross-faults, or by slight angular changes in the courses of the great faults." This strip of country is thirty to forty miles wide, and the intervals between the fractures or faults are from five to six miles wide. All have a southeast dip; a portion of the Carboniferous formation forms the southeastern brow of each, overlooking to the southeast Lower Silurian limestone, and resting on Devonian and Silurian, which come into view to the northwest.

According to the Professors Rogers, these faults in southwestern Virginia, which were early described by them, occur along the axes of plications, instead of in monoclinal strata. (Trans. Amer. Assoc. Geol. Nat., p. 494.)

2. *The facts in accordance with the supposed origin.*—The Professors Rogers have referred to waves in the earth's liquid interior for an

explanation of the facts mentioned. Elie de Beaumont and some other geologists have attributed these effects, and especially the elevation of mountains, to the contraction of a cooling globe,—the last of the above-mentioned causes; and this appears to be the only one adequate for the results.

The facts observed correspond precisely with the effects of the cause mentioned; and it is hardly necessary for those readers who have in mind the structure of the Appalachians as it has been explained, to enter here into details. On page 410 it is shown that the force in the case of the Appalachian region acted in a direction from the Atlantic Ocean,—that is, at right angles to the axial direction of the folds. It follows, therefore, that the subsiding area which determined the formation of the folds and the uplifts was beneath the Atlantic Ocean.

3. *Flexibility of rocks.*—It is a fact recently established that there is scarcely any material so solid that when in broad tabular masses it will not become flexed under a heavy pressure very gradually applied. By "very gradually" should be understood that degree of extreme slowness which has so often been exemplified in geological history, and which is the most common of nature's methods of progress. The rock or other solid, though apparently inflexible, will undergo, under such conditions, a molecular movement, adapting it to its new condition. Even brittle ice, as stated on p. 673, becomes flexed by its own weight if a slab be supported by only one end. There is no doubt that if ice covered a lake to a thickness of a dozen or more feet, and a slowly-accumulating pressure to a sufficient amount could be brought to bear against one side of it, the ice might be plicated over its surface as boldly and numerously as the formations of the Appalachians.

Fractures have usually been produced in the course of the flexing of the earth's crust; a violent exertion of pressure under such circumstances would naturally produce them on a grand scale; but they are not an inevitable result of the process of plication. If the rocks were moist,—as has been the case during these upturnings,—the plication would take place the more readily. If they were heated also, and if by this means they were penetrated by superheated water or steam, the mobility of the particles would be still greater, and they might even have, as observed on p. 708, a degree of plasticity.

In general, the arenaceous and argillaceous beds which have been folded were not at the time firmly consolidated, but derived their consolidation from the heat which escaped from below during the progress of the movement, and which was the cause of metamor-

phism where the plications were most numerous. Limestone is always in solid layers unless quite impure.

4. *Formation of valleys.*—The plication of the earth's crust produces alternating depressions and elevations, unless the folds are pressed together into a close mass. The depressions are *synclinal valleys*. The minor valleys of this kind are generally obliterated by subsequent denudation; and often even the summits of ridges, under this latter agency, may consist of the rocks of a synclinal axis. Besides synclinal valleys, there are often also *monoclinal* valleys (p. 720). In addition, there are wider depressions lying between distant ranges of elevations which were produced through a gentle bending of the earth's crust (made up of plicated strata or not); and these great valleys or depressions (like the Mississippi and Connecticut valleys) may be called *geoclinal*, the inclination on which they depend being in the mass of the crust, and not in its *strata*.

5. *Elevation of mountains.*—The force engaged in producing the great systems of plications over the earth is sufficient for the elevation of mountains of all heights.

Mountain-chains are not made of igneous ejections, except occasionally in some small portions.

They are not a result of the mere accumulation of a series of sedimentary beds; for, when the last layer of such a series is laid down, the whole is still under water, and some force is required to raise them above the ocean, so as to entitle them to a place among the earth's mountains. And generally there are plications and metamorphism attending upon such elevation, due, directly or indirectly, to the same powerful agency. While, then, they consist mostly of sedimentary beds, altered or unaltered, they have been raised to their places by an adequate force. Mountains lifted by lateral pressure or tension within the crust would be supported as raised; they would not be resting on a sea of unstable vapors, but would have a solid basis,—that by the movement of which they were elevated.

6. *Epochs of elevation separated by long intervals.*—Mountain-chains are not the work of the earlier periods of the globe alone, when, it is believed, the earth's fires were most active, but of particular epochs in the course of all its ages; and the loftiest of the globe received much the larger part of their altitude after the close of the Mesozoic era (p. 503). Plications and disturbances of strata, and metamorphism, have also occurred at intervals in all ages, and the two sets of phenomena were partly cotemporaneous.

The special epochs of great uplifts and foldings in eastern North America have been shown to be—(1) the later part (or close of the

Laurentian period) of the Azoic age; (2) probably, the close of the Lower Silurian, for part of the Green Mountains; (3) the close of the Palæozoic era, for the greater part of the Appalachian region, between Labrador and Alabama. It appears, then, that the tension within the crust continued accumulating through long intervals, before it reached that degree which was sufficient to bring on an epoch of plication, uplift, and metamorphism. No one will pretend to count the thousands of centuries between the Azoic era, or the close of the Lower Silurian, and the close of the Palæozoic era. In Europe, and probably in western America, the intervals were less; moreover, great uplifts, plications, and metamorphism took place in these regions after the Palæozoic; but in every case the period during which tension was accumulating, preparatory for the epoch of disturbance, was a long one; for the epochs of the elevation of mountains, even in Europe, are but few in number in the whole course of past time.

7. *Oscillations and minor uplifts.*—But during this period of accumulating tension other and minor effects were apparent. Oscillations of the crust, causing changes of level, were going on unceasingly, and they are yet in progress. The alternations of level through the Palæozoic in North America require no other explanation. They were part of the indications of that living and growing force which was to exhibit its grandest results after the Carboniferous age had ended.

8. *The water-line of the ocean liable to variations from oceanic subsidences.*—As all parts of the earth, oceanic as well as continental, must have participated in the changes of level, the water-level was ever fluctuating like the land-level; and hence it is not safe to measure the latter always by the former, as is too commonly done. Many of the apparent elevations may have been due to a deepening of the oceanic basin,—which has nearly three times the area of the land (p. 10),—and some of its apparent subsidences may have been caused by an elevation of its bottom. It is probable that at least 1000 feet of the height of the continents—the average height of the land of the globe—has arisen from the increase in the depth of the ocean which took place during the successive Palæozoic, Mesozoic, and Cenozoic eras.

9. *Mountains small elevations compared with the extent of the globe.*—It should be remembered, in this connection, that mountains are relatively to the size of the earth but little ridgelets on its surface. A chain 10,000 feet high would stand up only *one-tenth of an inch* on a globe 110 feet in circumference, or 35 feet in diameter,—as large as many a capacious house; and *one-hundredth of an inch* would

correspond on such a globe to the mean height of the continents. If the Rocky Mountains on a globe of this size were given their actual slope (equal on the east side to two or three feet in 5000 feet of length), they would be hardly recognizable. The highest peaks of the Appalachians would have a height of only *one-sixteenth of an inch*, and the highest of the globe, of only *three-tenths* of an inch. A change of level in the crust of 100 feet, which might, in the earlier geological ages, have lifted a large part of a continent out of the sea, would be represented by *one-thousandth of an inch* on the same globe. The movements for such effects would relatively, therefore, be exceedingly small. Considering the length of time which must have elapsed since the crust of the globe was first formed and through which contraction has been effecting its changes, and the vastness of the force that would thus be produced in the crust of a globe 25,000 miles in circumference, it may rather occasion surprise that the highest summits stand only 30,000 feet above the ocean's level, and less than 100,000 feet above the lowest depths of the oceanic basin.

10. *Courses of elevations in a region the same in different periods.*—The elevations and strike of the rocks in northern New York, which date from the Azoic age,—the first emergence of the Green Mountains, dating from the close of the Lower Silurian,—the plications, elevations, and metamorphism of the larger part of New England, dating from the close of the Palæozoic era,—the formation of the trap ridges of the Connecticut River valley, dating from the middle Mesozoic era,—have the same general direction. The Mesozoic trap ridges and the plications and uplifts of the Appalachians in Pennsylvania are also nearly parallel; and the same is true of the corresponding elevations in Virginia. These few examples are sufficient to illustrate the principle stated.

11. *Courses of elevations in a region not the same in different periods.*—Europe contains many examples of this diversity of direction in the same region: on page 533 a case of this kind in the Alps is mentioned. It seems natural that the elevating force should vary somewhat its direction with the progress of time, or, if remaining the same, that it should encounter a difference of resistance which should lead to a result unlike those in former periods.

12. *Courses of elevations different in the same period.*—The Mesozoic trap ridges and sandstone of Nova Scotia trend nearly northeast, those of the Connecticut valley north-by-east, those of Pennsylvania east-northeast, and those of Virginia northeast-by-north; and yet there is every reason to believe that they belong to the same period of origin. The Appalachian chain varies much in directions

southwest of New York; and there is no evidence that this difference is attributable to a difference of age.

While the plications of the rocks of New England are in the main nearly north-by-east in course, as shown by the strike of the rocks, there is a region in southern Connecticut where the strike is transverse to this direction, or parallel to Long Island and the course of the Appalachians in Pennsylvania; from which it may be inferred that, cotemporaneously with the action of forces from the eastward producing the prevailing plications of New England, a force was also acting from the southward, or at right angles to its southern coast. The complexity of directions in the White Mountains may not be owing to a difference of age, but to the combined action of forces from these two directions.

13. *The theory here adopted not in the main hypothetical.*—In attributing the plications of the earth's crust and the elevation of most mountains to a lateral pushing movement or tension within the crust, there is nothing that is hypothetical. The statement is the expression simply of a fact. The conclusion that this tension is due to the contraction of a cooling globe has not yet been fully established. It is here adopted because no other that is at all adequate has been presented. The cause must have been one which would have produced an increasing amount of tension through the passing periods, causing oscillations of the crust and minor uplifts in the course of those long periods, and then a great catastrophe, or an epoch of plications, metamorphism, and grander uplifts, as a result of the great increase; then another slow increase and another catastrophe; then others; and a series of similar but more or less independent catastrophes in distant parts of the globe, raising, as late as the Tertiary period, many of the earth's great mountain-chains,—but one which should cause only minor oscillations and uplifts in more recent times, since the earth has now a degree of stability unusual in the past ages (p. 586). And no cause answers to these demands, so far as known, but the one mentioned,—the *contraction of a cooling globe.*

2. FRACTURES, FAULTS, AND STRUCTURAL PECULIARITIES.

1. Fractures.

The following are some of the causes of fractures:—

1. *Drying through the heat of the sun,* as in the formation of cracks in mud or earth.—Such cracks are usually but a few inches deep,—though in the soil of some prairies they occasionally

extend to the depth of a yard or more, and are two or three inches wide at top.

2. *Baking effect from the heat of igneous ejections.*—The adjoining rock, especially if argillaceous, is often cracked into small columns of five or six sides, or more, while at the same time hardened.

3. *Loss of heat.*—Contraction from the loss of heat often produces a reticulation of vertical cracks, which are usually too narrow even for the insertion of a knife-blade, unless the rock contain considerable moisture. To this cause is to be attributed the division of basalt or trap into columnar forms. (The size of the columns is, however, dependent on concentric crystallization within the mass, as explained on p. 98.)

4. *A removal of the support of rocks by undermining or other causes.*

5. *Pressure of a column of liquid rock,* as in volcanoes.

6. *Expansive force of vapors, especially when suddenly evolved,* as in volcanic regions.

The preceding are local causes of fracture. The last-mentioned is an exception to this, according to those geologists who attribute to vapors the elevation of mountains.

7. *Tension within the earth's crust,*—the same agency which has been explained on a preceding page as the true source of its plications and of the uplifting of mountains. Fractures have been made, through this means, of all extents, from those intersecting single layers, to profound breaks reaching down to regions of internal fires. In the plication of the rocks, fractures are most likely to be produced along the axes of the folds where the flexure is greatest,—those of the upward or anticlinal flexure opening upward, and those of the downward or synclinal flexure opening downward. If the latter extend through to the surface, they may give exit to melted rock. In periods of metamorphism, the lateral pressure causing the plications appears in general to have so closed up the fractures made, that igneous ejections were rare. It is not certain that any took place during the metamorphism of the Appalachian region; though subsequently, after the rocks had been stiffened by crystallization, the sinking of the geoclinal valleys occupied by the Mesozoic sandstone formation gave origin to a great profusion of trap ejections (p. 430).

Direction of fractures.—Fractures, in a region elevated by any method of pressure, tend to form, as shown by Hopkins, in a direction at right angles to the line of greatest strain or pressure, and also, in many cases, in a second direction transverse to this, making two systems, a primary and a subordinate.

2. Faults.

The several causes which may produce fractures through layers or strata may also cause faults, and the profounder the fractures the more extensive the faults that may result.

In general, there is a dropping down of the rock on one side of the fracture by gravity; and, where the fault is a sloping one (as in fig. 978), the mass on the upper side usually slides down the sloping plane. But, under the action of the pressure which has plicated the earth's crust and lifted mountains, the *reverse* movement has not been uncommon. The figure referred to is an example; and, by the upthrow, rocks of the Lower Silurian have been carried up to the level of those of the Subcarboniferous. Similar faults may occur along the axes of plications as described by the Professors Rogers.

In faulting, there may be either a *vertical* or *lateral* slide, or an *oblique* one. The inequality of the faulted parts of the veins represented in the figures on page 121 is accounted for on the ground of a lateral or oblique slide.

The strata sometimes have a different dip on the sides of a fault (figs. 96, 97). This may arise in different ways.

1. The plane of fracture may not have the same slope in its different parts, so that in either a vertical or lateral slide parts of unequal dip are brought together.

2. The rocks may open at the fault, and the parts be adjusted together by wear of the sides during the downthrow or uplift; and any portion of the fissure remaining open may be filled by the rubbish thus produced.

3. Wedge-shaped plates, larger below, may separate and fall, leaving the rock either side of the vacated space to be pressed together by the breaking-force.

4. Fractures converging downward may separate wedge-shaped masses; and the rock on one side or the other may fall off some degrees, while the wedge settles into its new position by gravity, and is adjusted to it by friction in the descent. If the rock to be faulted has a considerable dip transverse to the direction of the force, lateral slides would be of very common occurrence.

5. Plications and uplifts may take place, after a profound fracture in the rocks, on one side of the fracture, and not on the other. The abrupt transition in many places between the plicated region of the Appalachians and the slightly-tilted rocks of the country northwest of them can have no other explanation.

3. Structural peculiarities: slaty cleavage and jointed structure.

1. *Slaty cleavage.*—Slaty structure (exemplified in figs. 89 to 91, p. 101) has been shown, by Sharpe, Sorby, Darwin, and others, to be

a result of the pressure in action during an uplift. The slates are transverse to the force. The pressure tends to turn all pebbles or particles so as to place their flatter side in this transverse position, and any bubbles present become flattened out in the same way. Again, in all such action, force taking place in oscillations would tend to cause transverse lamination.

The laminated structure of ice has been explained by Tyndall on the same principle (p. 675). Tyndall has proved by experiment that slaty cleavage may be produced by means of pressure in white wax, clay, and similar substances, when they are left free to expand in directions transverse to the pressure.

When argillaceous and arenaceous layers alternate, the former may receive the slaty structure and the latter not; because the arenaceous layers, if not too firmly solidified, can accommodate themselves to the new condition by motion among their partially adhering particles of sand; if firmly consolidated, only joints will be produced, though in some varieties they may be so numerous as to occasion a coarsely laminated structure.

2. *Joints.*—Joints are due to the same cause as slaty cleavage, and may occur in slaty as well as other rocks.

Two systems at right angles to one another often result from one action, but that in the line of movement is much the least distinct.

Subjection to pressure from different directions, in different periods, would produce different systems of joints, and, in slates, sometimes a new direction of cleavage.

3. EARTHQUAKES.

1. General characteristics.—Earthquakes are vibrations of the earth's crust. The vibrations, begun at a line of fracture, or by a sudden movement or shock of whatever kind, are conveyed in the rocky crust, just as the sound of a scratch at one end of a log is carried to the other. If the ear be placed near the ice in winter, it will hear a crack made in it, although miles off. If the earth's crust suffer an abrupt fracture somewhere in its depths where tension has long been increasing and has finally forced a relief, the vibration may move on through a hemisphere, and will be almost regardless of the mountains on the surface.

Earthquakes are of two kinds:—

(1.) A simple vibratory movement, without any permanent displacement of the rocks.

(2.) A vibration accompanying an uplift.

The latter is far the most violent, as the simple impulse of vibration has an additional onward progression equivalent to the uplift or displacement.

Besides these wave-movements, there are also, in most cases, the very rapid wave which gives sound to the ear. The sound-wave may be felt before the translation-wave, and may travel farther. At the shock of St. Vincent, in 1812, sounds like thunder were heard over several thousand square miles in the Caraccas, the plains of Calaboso, and on the banks of the Rio Apure. At the Lima earthquake, in 1746, a subterranean noise, like a thunder-clap, was heard at Truxillo, where the earthquake did not reach.

The rate will vary with the elasticity of the rock, and somewhat, also, with the elevations over the surface.

2. **Regular progression in earthquakes.**—Regular progression may be a usual fact, although not generally observed. Professor Rogers has shown that an earthquake, on the 4th of January, 1843, traversed the United States from its northwestern military posts, beyond the Mississippi, to Georgia and South Carolina, along an east-southeast course, Natchez lying on the southern border and Iowa about the northern. The rate of travel ascertained was thirty-two to thirty-four miles a minute.

3. **Phenomena attending earthquakes.**—(1) Fractures of the earth, sometimes of great extent; (2) subsidences or elevations of extended regions, and draining of lakes; (3) displacements of loose rocks, and, where a mass overlies another and is not attached to it by its precise centre, a partial revolution, resulting from an onward impulse; (4) destruction of life in the sea, on the same principle that a blow on the ice of a pond will stun or kill the fish in the waters beneath; (5) production of forced waves in the ocean; (6) destruction of life on the land. Destructions of cities and of human life have been too often recounted to need special illustration in this place.

The elevations that take place are sometimes spoken of as *effects* of an earthquake, although not properly so. Vibration may be attended by fractures and uplifts; but these effects result from the cause that produces the shaking.

Some of the elevations and subsidences that have attended earthquakes are mentioned on page 588.

4. **Earthquake oceanic waves** have been alluded to on page 655. One or two additional examples of their effects may here be added. In 1755, accompanying the Lisbon earthquake, the sea came in in a wave 40 feet high in the Tagus, 60 at Cadiz, 18 on the

shores of Madeira, 8 to 10 on the coast of Cornwall. One in 1746, on the coast of Peru, deluged the sea-port Callao, and the city of Lima seven miles from the coast, sunk 23 vessels, and carried a frigate several miles inland. Two hundred shocks were experienced in 24 hours. The ocean twice retreated, to rush in a lofty wave over the land. The shock to a vessel from an earthquake wave is as if it had received a heavy blow or had struck a rock.

According to Professor Bache, the oceanic waves, produced by the great earthquake at Simoda (Japan) in 1854, crossed the Pacific, and were registered, as to their number, intervals, and forms, on the self-registering tide-gauges of the Coast Survey along the coast of Oregon and California; and from the data thus afforded he was enabled to calculate the mean depth of the intervening ocean, stated on page 12.

5. **Causes of earthquakes.**—(1.) *The tension and pressure by which the great oscillations and plications of the earth's crust have been produced.*—The effects of this tension have not yet wholly ceased. This is probably the most general cause of earthquakes.

The uplifting of the formations, moreover, must have always left the interior of the crust in a state of unstable equilibrium; and any incipient slide in the progress of time along an old fracture, or between tilted beds, would be attended by an earthquake-shock.

All are familiar with the cracking sounds occurring at intervals in a board floor of a house, and arising from change of temperature, especially in a room in winter that is heated during the day; and with the more common sounds of similar character from the jointed metallic pipe of a stove or furnace given out after a fire is first made, or during its decline. In each case, there is a strain or tension accumulating for a while from contraction or expansion, which relieves itself, finally, by a movement or slip at some point, though too slight a one to be perceived; and the action and effects are quite analogous to those connected with the lighter kind of earthquakes.

(2.) *Any cause of extensive fracture or movement,*—as the undermining of strata, the sudden evolution of vapors, etc.

(3.) *Tidal waves in the internal igneous material of the globe.*—This hypothesis supposes the material of the interior to be sufficiently liquid to have waves, and the crust to be thin.

Some investigations by Professor Alexis Perrey, of Dijon, France, seem to indicate that there is a periodicity in earthquakes synchronous with that in the tides of the ocean,—the greatest number occurring at the season of the high tides of spring and autumn. If this be sustained by further research, the cause must be admitted

to be a true one. Its sole effect, however, may be to determine the occurrence of earthquakes where another more powerful agency, as that first mentioned, had prepared the conditions and made all ready for the movement. If there are internal tides, and they have this much of power, earthquakes would be most frequent at the semi-annual periods of the highest tides, as Professor Perrey concludes to be the fact.

4. EVOLUTION OF THE EARTH'S GREAT OUTLINES AND RELIEFS, AND OF THE SUCCESSIVE PHASES IN ITS PROGRESS.

1. Evolution of the Earth's Outlines and Reliefs.

1. *General laws as to arrangement.*

In the chapter on the General Features of the Earth (pp. 9–39), it has been shown that there is a system in the arrangement of its reliefs and outlines. Whatever force, therefore, originated the great mountain-chains originated not merely independent mountains, but the system of reliefs of the sphere.

The general principles connected with this system, announced in the chapter referred to, or brought out in the later pages of the volume, are the following:—

I. The continents have mountains along their borders, while the interior is relatively low; and these border mountain-chains often consist of two or three ranges elevated at different epochs.

II. The highest mountain-border faces the largest ocean, and conversely.

III. The continents have their volcanoes mainly on their borders, the interior being almost wholly without them, although they were largely covered with salt water from the Azoic age to the Tertiary. Also metamorphic rocks later than the Azoic are most prevalent near the borders.

IV. Nearly all of the volcanoes of a continent are on that border which faces the largest ocean.

V. The strata of the continental borders are for the most part plicated on a grand scale, while those of the interior are relatively but little disturbed.

VI. The successive changes of level on coasts, even from the Azoic age to the Tertiary, have been in general parallel to the border mountain-chains; as those of the eastern United States, parallel to the Appalachians, and those of the Pacific side, as far as now appears, parallel to the Rocky Mountains.

VII. The continents and oceans had their general outline or form defined in earliest time. This has been proved with regard to North America from the position and distribution of the first beds of the Lower Silurian,—those of the Potsdam epoch. The facts indicate that the continent of North America had its surface near tide-level, part above and part below it (p. 196); and this will probably be proved to be the condition in Primordial time of the other continents also. And, if the outlines of the continents were marked out, it follows that the outlines of the oceans were no less so.

VIII. The prevalent courses of coast-lines, mountain-chains, and groups of islands over the globe are two,—one between the northeast and southwest, and the other between the northwest and southeast (p. 30).

IX. In the courses of the earth's outlines, while there are two prevalent trends, there are very commonly curves:—in some cases a gradual curve, as from E.N.E. to N.N.E., as in the great central chain of the Pacific, or from N.E. to E. and then to N.N.E., as in the line from New Zealand to Malacca (p. 32); in others, a series of several curves, meeting one another nearly at right angles, as in the island-ranges off the Asiatic coast (p. 36).

X. The earth towards or about the equatorial regions is belted with oceanic waters separating its northern and southern continents, passing through the East Indies, Red Sea, Mediterranean, and West Indies; and this region is remarkable for its volcanoes (p. 686).

The preceding are some of the comprehensive characteristics of the globe which exhibit the system that pervades its physiognomy and illustrate the manner in which this system was educed.

2. *Deductions from the positions of the reliefs.*

1. The situation of the great mountain-chains, mainly near the borders of the continents, does not indicate whether the elevating pressure acted within the continental or oceanic part of the earth's crust. But the occurrence between the principal range and the sea-coast of the larger part of the volcanoes (and, therefore, of the profound and widely-opened fractures) of these borders, of the most extensive metamorphic areas, and the closest and most numerous plications of the strata, as so well shown in North America, are sufficient evidence that the force acted most strongly from the oceanic direction.

2. The relation between the extent of the oceans and the height and volcanic action, etc. of their borders proves that the amount

of force in action had some relation to the size and depth of the oceanic basin. The Pacific exhibits its greatness in the lofty mountains and volcanoes which begirt it.

3. In such a movement, elevation in one part supposes necessarily subsidence in another; and, while the continental was the part of the crust which was elevated, the oceanic was the subsiding part.

The oscillations, plications, and elevations alluded to began in the Azoic age: hence the conclusion that the oceanic basins and continents were early outlined is unavoidable. The sinking of the ocean's bed and the rising of the continents were concurrent effects of one cause. The raising of mountains reached its climax in the Tertiary period: from that time the effects have declined.

4. If, then, the continents were from the beginning the nearly stable areas (as appears also from the absence of volcanoes from their interior, while they abound in the oceans), the pressure of the subsiding oceanic portion has acted against the resisting mass of the continents; and thus the border between them has become elevated, plicated, metamorphosed, and embossed with volcanoes.

5. The position of the Urals between Europe and Asia is in accordance with the theory; for in a continent so broad from east to west as the Orient, the tension and movements within the continental crust would naturally occasion some elevations.

6. While the Alps may have been elevated by the tension within the oceanic crust, the Juras appear to have been a reacting effect of elevation in the region of the Alps; for the plications are most numerous towards the Alps, instead of towards the ocean.

7. The cause of this tension and pressure within the crust has been attributed, on a former page, to the secular refrigeration of the globe. No other cause presents itself that can comprehend in its action the whole globe and all time.

The universality of this cause is also exhibited in the cotemporaneousness of even some of the minor oscillations of the surface of different continents,—as, for example, the condition of submergence in Europe and America preceding the Coal period, which favored the formation of the Subcarboniferous limestone on both; the condition of progressing emergence required for the succeeding Millstone grit; and then that of the general, though slight, emergence requisite for the Coal period itself (p. 394).

It has been shown (p. 569) that after the Tertiary period the system of oscillations of the earth changed to a high-latitude system, both in the northern and southern hemispheres. This, again, exhibits the comprehensiveness of the great cause. It is probable

that these transverse or latitudinal oscillations, while most prominent in the higher latitudes, also had their lower-latitude effects; that they resulted in deepening the transverse seas that divide the northern and southern continents. For the occurrence of Post-tertiary animals on Sicily, Malta, and Gozo, in the Mediterranean, similar to those of Africa, is strong testimony, as some writers have observed, that these islands were joined to the mainland on the south even in the last period of geological history, when the Age of Man was opening. The barrier coral reefs and coral islands of the East and West Indies indicate as recent depressions in those inter-continental seas. Even the origin of the British Channel, as some have thought, may be of the same period, if the identity of European and British Post-tertiary mammals is not to be explained by independent creations in the now disjoined lands. Moreover, the Pacific Ocean, within the tropics, has registers of subsidence all over it, in its coral islands.

3. *Deductions from the courses of the reliefs and outlines.*

The prevalent northeast and northwest courses of trends, the curves in the lines varying the direction from these courses, and the dependence of the outlines and feature-lines of the continents and oceanic lands upon these courses, are the profoundest evidence of unity of development in the earth. Such lines of uplift are lines of fracture, or lines of weakest cohesion; and therefore, like the courses of cleavage in crystals, they show by their prevalence some traces of a cleavage-structure in the earth,—in other words, a tendency to break in two transverse directions rather than others.

Such a cleavage-structure would follow from the nature of the earth's crust. The crust has thickened by cooling until now scores of miles through, and very much as ice thickens,—by additions to its lower surface. Ice takes on a columnar structure, perpendicular to the surface, in the process, so as often to break into columns on slow melting. The earth's crust contains as its principal ingredient the cleavable mineral feldspar; and as the crystals of this mineral usually take a parallel position in a granite, so that the granite of a quarry has its directions of easiest fracture, so it might be in the cooling crust. This appears the more probable when it is considered with what extreme slowness the thickening of the crust has gone on, and the immeasurable length of time it has occupied.

There are three elements at the basis of the earth's features. First, a *geographical* one,—the positions and extent of the con-

tinents, or comparatively stable areas, in relation to the oceans, or more subsiding areas; the second, *structural*,—the system of cleavage-structure; the third, *dynamical*,—the tension in the crust itself accumulating most through the subsiding of the oceanic basins.

The features of the oceanic basins and the position of the continents determine the general bearing of the tension; and the cleavage-structure, or courses of weakest cohesion, tends to give direction to its effects. The North Atlantic follows one of the cleavage-courses, the Pacific another (page 36); North America is bounded by the two, and hence its triangular form. See, further, on these lines, pages 30 to 39.

The courses of the rents or uplifts in such a crust will depend on the direction of the tension in connection with the cleavage; just as in a piece of cloth the rents from stretching it will vary with the direction of the force.

Force exerted at right angles to the lines of structure, and equal along the line, would produce a straight series of rents or uplifts (figs. 11, 12, p. 19).

If not equal along a given line, the rents might together make an oblique or curving series (figs. 14, 15, p. 19). If the tension were oblique to the structure-courses, the series of rents would be oblique, and, as above, either straight or curved.

Hence curves are necessarily in the system.

The coincidence between the trend of the Pacific (northwest and southeast), the mean trend of the Pacific islands (p. 34), and the axis of the coral-island subsidence (p. 587), shows that the ocean in its movements has been one great area of oscillation. The central curving range, 6000 miles long, lies on the southern side of the axis of this great approximately elliptical area. The tension in this subsiding area itself appears here to be the cause of the long curve.

The double or triple system of curves around Australia, from New Hebrides, or perhaps northern New Zealand, to New Guinea and Timor, are such as might arise from the Pacific tension, acting against that stable continental area of Australia; for they are concentric with it; and the branch of the central Pacific chain leading off westward through the Carolines has been shown, on page 34, to conform to this Australian system. The rising curve from Java, through Sumatra, suggests that here the oceanic basin on the other side of Australia (the Indian Ocean) has brought tension to bear against the Asiatic continental area; and this is further confirmed by the fact that the deep-water channel separating the Australian seas from the Asiatic passes just north of New Guinea and Timor and south of Java.

The East Indian Archipelago lies between the North Pacific and the Indian Ocean; and the two, along with the reacting stable continental areas, have together modelled out the group. The West Indian Archipelago has a similar position between the North Atlantic and the South Pacific, and hence the resemblances to the East Indian pointed out on page 37.

The curves along eastern Asia, in the islands and continental mountain-ranges (page 36), seem to show that the tension across the Pacific area, which produced the curves, was unequal along different lines. The courses and positions of the groups of Pacific islands prove that the bottom has its ranges of southeast and northwest elevations and depressions, crossing the ocean; and this would occasion the unequal tension required.

Between the directions of the structure-lines and the directions of the acting force, as determined by the oceanic and continental areas, the origin of the prevalent trends and of their frequent curving courses may therefore be explained.

4. *Application to North America.*

The geological progress of North America was an evolution of a continent under the two great systems of forces, the Atlantic and the Pacific. The Appalachians, with their many folds, are a proof of the reality of the former; and the Rocky Mountains, with their parallel ranges,—the great volcanic chain and Sierra Nevada near the coast, the double crest about the summits, and other ranges across an area one thousand miles in breadth,—are equally a proof of the reality and vast power of the latter. The Azoic land from Lake Superior to the Arctic was the result of an Azoic action of the Pacific force; and that from Lake Superior to Labrador, of the Atlantic force. This, as shown on page 136, was the Azoic nucleus, from which the growth went onward, mainly through the oscillating energies to the southeast and southwest. This fixed the position of Hudson's Bay, for it is between the arms of the V. This enlarged the continent to the southeast and southwest, spreading out the strata under the oscillations occasioned, finally doubling the V by adding the Appalachians and the Rocky Mountains, and tripling it later on the west by the Cascade and other ranges.

Effects of the meeting and crossing of the two forces over North America, that from the southeast and that from the southwest, are seen in the line of the Illinois uplifts and Florida (pp. 320, 531), of the latter system, intersecting the Appalachian chain in eastern Tennessee. The area of the uplifted Lower Silurian about Cincinnati

is intermediate between the two; and it is interesting to observe that its distance from the small Atlantic is 500 miles, from the great Pacific 2000; a ratio of 1:4.

The Azoic nucleus of North America, spreading southward, formed a peninsula in northern New York. Even this bend in the nucleus continues in the finished continent, for New England has the same outline. Its east and south coast-lines are but a repetition of the east and south coast-lines of the old Azoic peninsula. This exact copying of the nucleus by the growing continent proves, better than all other evidence, the grand fact that the progress has been through oscillating forces acting against the stable Azoic nucleus, and also that the system of evolution has been under profound law.

2. Origin of the Successive Phases in the Earth's Progress.

1. **Epochs.**—The epochs in geological history were marked by transitions in the strata and by more or less complete exterminations of life. These transitions, as has been already explained (p. 398), were directly connected with oscillations in the water-level about the continental areas; and this water-level was changed by elevations and subsidences either in the continental or the oceanic portion of the crust, or the two united (p. 723). Violent paroxysmal uplifts and downthrows, and also effusions of heat, were among the events here included, as well as the gentler changes of level that were barely apparent with the passing of a century. But far the larger part even of the seemingly abrupt transitions required only the latter.

The succession of epochs in history and the development of the earth's features, were, therefore, concomitant results in the same plan of evolution.

2. **Climate.**—Three causes have been presented to account for the cooling of the climate of the globe in past time:—

1. *The decreasing density and cloudiness of the atmosphere*, through a diminution of the proportion of carbonic acid and moisture.

2. *The increasing extent and height of the land.*

3. *The secular refrigeration of the globe.*

Two other supposed causes are sometimes brought forward:—

4. *A change in the earth's poles.*—Such an event would only change the location of the frigid zone or polar climate. When it has been proved that there was a polar climate anywhere in the Palæozoic ages, and what its location was, it will be soon enough to arrange this among possible causes. Astronomers deny its possibility.

5. *A passing of the earth through warm regions in space during its earlier*

eras.—This cause is so far within the region of the hypothetical as hardly to merit consideration until all others admitting of investigation have been proved insufficient.

The first of these causes is beyond doubt a real one; yet its effects must have been too small, especially after the Carboniferous age, to have produced the whole amount of change which took place.

The second is also of undoubted value, as explained on page 45. To appreciate its influence, it is necessary to suppose the existing globe with its climates changed in its lands. For example, to produce the climate of the Coal period, the amount of land should be reduced one-half in area, far the larger part of this be brought nearly to the ocean's level, all the highest mountains be lowered or levelled, and the greatest elevations made not to exceed 6000 or 8000 feet, and then to be of comparatively limited extent.

The Polar lands were in existence, as the coal fields show, but may have been comparatively small. Facts seem to prove that such changes might reduce the higher latitudes to the condition of Fuegia. But Fuegia has alpine plants within one thousand feet of the sea, and a mean temperature but little above freezing. The result is still not what the facts require; for there is no reason to believe that there was any alpine or sub-frigid vegetation at Melville Island, or that the plants differed essentially from those of Pennsylvania. This warm climate of the poles was hardly less striking in the middle Mesozoic. For, while Reptiles are especially characteristic of the tropics, there were Ichthyosaurs and Teleosaurs in the Arctic. Sir Edward Belcher found an Ichthyosaur on Exmouth Island, in latitude 77° 16′ N. and longitude 96° W., 570 feet above the present sea-level; and Captain Sherard Osborn found two bones of a species allied to the Teleosaur on Bathurst Island, in latitude 76° 22′ N. and longitude 104° W.

The third cause mentioned has unquestionably acted in the earth's history, if the globe was once in igneous fusion. But it may well be questioned whether by the commencement of the Silurian age the crust had not attained a thickness which would have rendered the internal fires no longer a source of heat for the earth's surface. That the heat issuing through the crust was so great at the poles in the Carboniferous age as to raise the mean temperature, by radiation into the atmosphere, from 40° F. to 60° F. (the climate probably required for the vegetation of the era), is not true; for the same amount of change in the temperate and tropical zones would have rendered them uninhabitable by most plants and animals. But some few degrees of heat may have been received

by the *waters of the ocean*,—especially if the crust beneath the ocean were originally thinner than the continental portion, as may be inferred from its being the portion which subsided most during the earth's contraction. A small change in the ocean would have produced great effects over the globe, through the oceanic currents.

The cooling of the climate of the earth is probably due to all three of these causes; but the exact effect of each in bringing about the result, it is impossible, in the present state of science, to estimate.

3. **Progress in the earth accords with the universal law of development.**—The general law at the basis of all development is strikingly exhibited in the earth's physical progress, as has been well shown by Guyot. The law is simply this:—Unity evolving multiplicity of parts through successive individualizations, proceeding from the more fundamental onward (see page 599).

The earth in igneous fusion had no more distinction of parts than a germ. Afterwards, the continents, while still beneath the waters, began to take shape. Then, as the seas deepened, the first dry land appeared, low, barren, and lifeless. Under slow intestine movements and the concurrent action of the enveloping waters, the dry land expanded, strata formed, and, as these processes went on, mountains by degrees rose, each in its appointed place. Finally, in the last stage of the development, the Alps, Pyrenees, and other heights received their majestic dimensions, and the continents were finished to their very borders.

Again, as to the history of fresh waters. The first waters were all salt, and the oceans one, the waters sweeping around the sphere in an almost unbroken tide. Fresh waters left their mark only in a rain-drop impression. Then the rising lands commenced to mark out the great seas, and the incipient continents were at times spread with fresh-water marshes, into which rills were flowing from the slopes around. As the mountains enlarged, the rills changed to rivers, till at last the rivers also were of majestic extent, and the continents were throughout covered with streams at work channelling mountains, spreading out plains, opening lines of communication, and distributing fertility everywhere.

Again, the first climates were all tropical. But, when mountains and streams were attaining their growth, a diversity of climate (essential to the full strength of the latter) was gradually evolved, until winter had settled about the poles as well as the earth's loftier summits, leaving only a limited zone—and that with many variations—to perpetual summer.

The organic history of the earth, from its primal simplicity to

the final diversity, has been shown to exemplify in many ways the same great principle.

Thus the earth's features and functions were successively individualized,—first the more fundamental qualities being evolved, and finally those myriad details in which its special characteristics, its magnificent perfection, and its great purpose of existence and fitness for duty, largely consist.

Conclusion.—The causes of the earth's movements which have been considered appear to explain the evolution of the prominent features of the globe; and the special history made out for North America may be safely regarded as an example of what will hereafter be accomplished for all the continents.

But Geology, while reaching so deeply into the origin of things, leaves wholly unexplained the creation of matter, life, and spirit, and that spiritual element which pervades the whole history like a prophecy, becoming more and more clearly pronounced with the progressing ages, and having its consummation and fulfilment in Man. It gives no cause for the arrangement of the continents together in one hemisphere (p. 10) and mainly in the same temperate zone, or their situation about the narrow Atlantic, with the barrier-mountains in the remote west of America and in the remote east of Europe and Asia, thus gathering the civilized world into one vast arena (p. 29); it does not account for the oceans having that exact relation in extent and depth to the land which, under all the changes, allowed of submergence and emergence through small oscillations of the crust, and hence permitted the spreading out of sandstones and shales by the waves and currents, the building up of limestones through animal life, and the accumulation of coal beds through the growth of plants,—and all in numberless alternations; nor for the various adaptations of the system of plants and animals to the wants of the last species in that system. Through the whole history of the globe there was a shaping, provisioning, and exalting of the earth with reference to a being of mind, to be sustained, educated, exalted. This is the spiritual element in geological history, for which attraction, water, and fire have no explanation.

COSMOGONY.

The science of cosmogony treats of the history of creation.

Geology comprises that later portion of the history which is within the range of direct investigation, beginning with the rock-covered globe, and gathering only a few hints as to a previous state of igneous fluidity.

Through Astronomy our knowledge of this earlier state becomes less doubtful, and we even discover evidence of a period still more remote. Ascertaining thence that the sun of our system is in intense ignition, that the moon, the earth's satellite, was once a globe of fire, but is now cooled and covered with extinct craters, and that space is filled with burning suns,—and learning also from physical science that all heated bodies in space must have been losing heat through past time, the smallest most rapidly,—we safely conclude that the earth has passed through a stage of igneous fluidity.

Again, as to the remoter period: the forms of the nebulæ and of other starry systems in the heavens, and the relations which subsist between the spheres in our own system, have been found to be such as would have resulted if the whole universe had been evolved from an original nebula or gaseous fluid. It is not necessary for the strength of this argument that any portion of the primal nebula should exist now at this late period in the history of the universe: it is only what might have been expected that the nebulæ of the present heavens should be turning out to be clusters of stars. If, then, this nebular theory be true, the universe has been developed from a primal unit, and the earth is one of the individual orbs produced in the course of its evolution. Its history is in kind like that which has been deciphered with regard to the earth: it only carries the action of physical forces, under a sustaining and directing hand, further back in time.

The science also of Chemistry is aiding in the study of the earth's earliest development, and is preparing itself to write a history of the various changes which should have taken place among the elements from the first commencement of combination to the formation of the solid crust of our globe.

It is not proposed to enter either into chemical or astronomical

details in this place, but, supposing the nebular theory to be true, briefly to mention the great stages of progress in the history of the earth, or those successive periods which stand out prominently in time through the exhibition of some new idea in the grand system of progress. The views here offered, and the following on the cosmogony of the Bible, are essentially those brought out by Professor Guyot in his lectures.

Stages of progress.—These stages of progress are as follow:—

(1.) *The* BEGINNING OF ACTIVITY IN MATTER.—In such a beginning from matter in the state of a gaseous fluid the activity would be intense, and it would show itself at once by a manifestation of light, since light is a resultant of molecular activity. A flash of light through the universe would therefore be the first announcement of the work begun.

(2.) *The development of the* EARTH.—A dividing and subdividing of the original fluid going on would have evolved systems of various grades, and ultimately the orbs of space, among these the earth, an igneous sphere enveloped in vapors.

(3.) *The production of the* EARTH'S PHYSICAL FEATURES,—by the outlining of the continents and oceans. The condensible vapors would have gradually settled upon the earth as cooling progressed.

(4.) *The introduction of* LIFE *under its simplest forms,*—as in the lowest of plants, and perhaps, also, of animals. As shown on page 396, the systems of structure characterizing the two kingdoms of nature, the *Radiate* of the Vegetable kingdom, and the *Radiate, Molluscan, Articulate,* and *Vertebrate* of the Animal, are not brought out in the simplest forms of life. The true *Zoic* era in history began later. As plants are primarily the food of animals, there is reason for believing that the idea of life was first expressed in a plant.

(5.) *The display of the* SYSTEMS *in the Kingdoms of Life,*—the exhibition of the four grand types under the Animal kingdom, being the predominant idea in this phase of progress.

(6.) *The introduction of the highest class of Vertebrates,—that of the* MAMMALS (the class to which MAN belongs),—viviparous species, which are eminent above all other Vertebrates for a quality prophetic of a high moral purpose,—that of suckling their young.

(7.) *The introduction of* Man,—the first being of moral and intellectual qualities, and one in whom the unity of nature has its full expression.

There is another great event in the Earth's history which has not yet been mentioned, because of a little uncertainty with regard to its exact place among the others. The event referred to is the first shining of the sun upon the earth. after the vapors which till

then had shrouded the sphere were mostly condensed. This must have preceded the introduction of the Animal system, since the sun is the grand source of activity throughout nature on the earth, and is essential to the existence of life, excepting its lowest forms. In the history of the globe which has been given on page 196, it has been shown that the outlining of the continents was one of the earliest events, dating even from the Azoic age; and it is probable, from the facts stated, that it preceded that clearing of the atmosphere which opened the sky to the earth. This would place the event between numbers 3 and 5, and, as the sun's light was not essential to the earliest of organisms, probably after number 4.

The order will, then, be—

(1.) Activity begun,—light an immediate result.

(2.) The earth made an independent sphere.

(3.) Outlining of the land and water, determining the earth's general configuration.

(4.) The idea of life expressed in the lowest plants, and afterwards, if not cotemporaneously, in the lowest or systemless animals, or Protozoans.

(5.) The energizing light of the sun shining on the earth,—an essential preliminary to the display of the systems of life.

(6.) Introduction of the systems of life.

(7.) Introduction of Mammals,—the highest order of Vertebrates,—the class afterwards to be dignified by including a being of moral and intellectual nature.

(8.) Introduction of Man.

Cosmogony of the Bible.—There is one ancient document on cosmogony—that of the opening page of the Bible—which is not only admired for its sublimity, but is very generally believed to be of divine origin, and which, therefore, demands at least a brief consideration in this place.

In the first place, it may be observed that *this document, if true, is of divine origin.* For no human mind was witness of the events; and no such mind in the early age of the world, unless gifted with superhuman intelligence, could have contrived such a scheme;—would have placed the creation of the sun, the source of light to the earth, so long after the creation of light, even on the *fourth* day, and, what is equally singular, between the creation of plants and that of animals, when so important to both; and none could have reached to the depths of philosophy exhibited in the whole plan.

Again, *If divine, the account must bear marks of human imperfection, since it was communicated through man.* Ideas suggested to a human

mind by the Deity would take shape in that mind according to its range of knowledge, modes of thought, and use of language, unless it were at the same time supernaturally gifted with the profound knowledge and wisdom adequate to their conception; and even then they could not be intelligibly expressed, for want of words to represent them.

The central thought of each step in the Scripture cosmogony—for example, Light,—the dividing of the fluid earth from the fluid around it, individualizing the earth,—the arrangement of its land and water,—vegetation,—and so on—is brought out in the simple and natural style of a sublime intellect, wise for its times, but unversed in the depths of science which the future was to reveal. The idea of vegetation to such a one would be vegetation as he knew it; and so it is described. The idea of dividing the earth from the fluid around it would take the form of a dividing from the fluid above, in the imperfect conceptions of a mind unacquainted with the earth's sphericity and the true nature of the firmament,—especially as the event was beyond the reach of all ordinary thought.

Objections are often made to the word "day,"—as if its use limited the time of each of the six periods to a day of twenty-four hours. But in the course of the document this word "day" has various significations, and, among them, all that are common to it in ordinary language. These are—(1) The light,—"God called the light day," v. 5; (2) the "evening and the morning" before the appearance of the sun; (3) the "evening and the morning" after the appearance of the sun; (4) the hours of light in the twenty-four hours (as well as the whole twenty-four hours), in verse 14; and (5) in the following chapter, at the commencement of another record of creation, the whole period of creation is called "a day." The proper meaning of "evening and morning," in a history of creation, is *beginning and completion;* and, in this sense, darkness before light is but a common metaphor.

A Deity working in creation like a day-laborer by earth-days of twenty-four hours, resting at night, is a belittling conception, and one probably never in the mind of the sacred penman. In the plan of an infinite God, centuries are required for the maturing of some of the plants with which the earth is adorned.

The order of events in the Scripture cosmogony corresponds essentially with that which has been given. There was first a void and formless earth: this was literally true of the "heavens and the earth," if they were in the condition of a gaseous fluid. The succession is as follows:—

(1.) Light.

(2.) The dividing of the waters below from the waters above the earth (the word translated *waters* may mean *fluid*).

(3.) The dividing of the land and water on the earth.

(4.) Vegetation; which Moses, appreciating the philosophical characteristic of the new creation distinguishing it from previous inorganic substances, defines as that "which has seed in itself."

(5.) The sun, moon, and stars.

(6.) The lower animals, those that swarm in the waters, and the creeping and flying species of the land.

(7.) Beasts of prey ("creeping" here meaning "prowling").

(8.) Man.

In this succession, we observe not merely an order of events, like that deduced from science; there is a system in the arrangement, and a far-reaching prophecy, to which philosophy could not have attained, however instructed.

The account recognizes in creation two great eras of three days each,—an *Inorganic* and an *Organic*.

Each of these eras opens with the appearance of *light:* the *first*, light cosmical; the *second*, light from the sun for the special uses of the earth.

Each era ends in a "day" of two great works,—the two shown to be distinct by being severally pronounced "good." On the *third* "day," that closing the Inorganic era, there was first the *dividing of the land from the waters*, and afterwards the *creation of vegetation*, or the institution of a kingdom of life,—a work widely diverse from all preceding it in the era. So on the *sixth* "day," terminating the Organic era, there was first *the creation of Mammals*, and then a second far greater work, totally new in its grandest element, *the creation of Man.*

The arrangement is, then, as follows:—

1. *The Inorganic Era.*

1st Day.—LIGHT cosmical.

2d Day.—The earth divided from the fluid around it, or individualized.

3d Day.— { 1. Outlining of the land and water.
2. Creation of vegetation.

2. *The Organic Era.*

4th Day.—LIGHT from the sun.

5th Day.—Creation of the lower orders of animals.

6th Day.— { 1. Creation of Mammals.
2. Creation of Man.

In addition, the last day of each era included one work typical of the era, and another related to it in essential points, but also

prophetic of the future. Vegetation, while, for physical reasons, a part of the creation of the third day, was also prophetic of the future Organic era, in which the progress of life was the grand characteristic. The record thus accords with the fundamental principle in history that the characteristic of an age has its beginnings within the age preceding. So, again, Man, while like other Mammals in structure, even to the homologies of every bone and muscle, was endowed with a spiritual nature, which looked forward to another era, that of spiritual existence. The *seventh* "day," the day of rest from the work of creation, is man's period of preparation for that new existence; and it is to promote this special end that—in strict parallelism—the Sabbath follows man's six days of work.

The record in the Bible is, therefore, profoundly philosophical in the scheme of creation which it presents. It is both true and divine. It is a declaration of authorship, both of Creation and the Bible, on the first page of the sacred volume.

There can be no real conflict between the two Books of the Great Author. Both are revelations made by Him to man,—the *earlier* telling of God-made harmonies coming up from the deep past, and rising to their height when man appeared, the *later* teaching man's relations to his Maker, and speaking of loftier harmonies in the eternal future.

APPENDIX.

A.—Animal Kingdom (p. 147).

1. *Distinctions between Animals and Plants.*—Since the discovery that the spores (or seed-cells) of some Algæ have locomotion like animalcules, and that there are unicellular locomotive plants (the Diatoms, etc.), some have thought that the two kingdoms of life blended together through their inferior species. But the fact is that they are diverse throughout,—the *opposite* but mutually dependent sides or parts of one system of life. The following are some of their distinctions:—

(1.) Plants excrete oxygen, a gas essential to animal life; animals excrete in respiration carbonic acid, a gas essential to vegetable life.

(2.) Plants take inorganic material as food, and turn it into organic; animals take this organic material thus prepared (plants), or other organic materials made from it (animals), finding no nutriment in inorganic matter.

(3.) Plants in passing from the unicellular state by growth *lose* in power, becoming usually fixed. Animals, in the same change, or in development from a germ, increase in power, augmenting in muscular force, and also, in the case of species above the lowest grade, in nervous force,—until an ant, for example, becomes a one-ant power, a horse a one-horse power; whence an animal is a self-propagating piece of enginery of various power according to the species.

(4.) The Vegetable kingdom is a provision for the storing away or magazining of force for the Animal kingdom. This force is acquired through the sun's influence or forces acting on the plant, and so promoting growth; mineral matter is thereby carried up to a higher grade of composition, that of starch, vegetable fibre, and sugar, and this is a state of concentrated or accumulated force. To this stored force animals go in order to carry forward their development; and, moreover, the grade of composition thus rises still higher to muscle and nerve (which contain nitrogen in addition to the constituents of the plant), and this is a magazining of force in a still more concentrated or condensed state. There are thus five states of stored force in nature,—three in *inorganic*, the solid, liquid, and gaseous; and two in *organic*, the vegetable and animal.*

The Animal type differs from the Vegetable (though not all animals from plants) in this: that, while the latter has the *superior-and-inferior* polarity of simple growth,—the stem growing upward and the root downward,—the former

* From a paper by the author on the "Anticipations of Man in Nature," published in the New Englander, May, 1859. Professor John Le Conte presented similar views at a later date, but independently, in a paper read before the American Association (in August, 1859).

has the *anterior-and-posterior*, or cephalic and anti-cephalic, polarity, connected with a well-developed nervous system. The Radiates among animals are allied in this respect to plants, being Animal representatives of the Vegetable radiate type; and this is the ground of the subdivision of the Animal kingdom stated on page 595 (§ *c*). Among the Radiates, the Polyps (the lowest of the three classes), in their modern and more typical kinds (see Appendix F), have a six-rayed structure, the Acalephs a four-rayed, the Echinoderms (or highest) a five-rayed, and these last look forward through their many unsymmetrical forms towards the cephalic polarity of the other sub-kingdoms.

2. *Protozoans.*—The two most common, and geologically the most important, subdivisions of the Protozoans, are mentioned on page 163. A few remarks on the classification of the group are added.

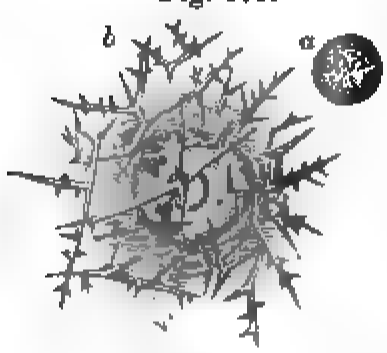
The Protozoans include those minute animal species in which neither of the four grand systems of the Animal kingdom (the Radiate, Molluscan, Articulate, and Vertebrate) is distinctly brought out. They represent life simply, or systemless. Their analogues among plants are the *Algæ*, which are also systemless; that is, are without the radiate structure typical of the Vegetable kingdom. *Protophytes* are only microscopic Algæ.

Although the grand systems in Zoology are unpronounced, there are still faint indications of them generally observable, or to be inferred from resemblances to the embryonic condition of higher species, and these are the most fundamental distinctions for their arrangement. The groups accordingly appear to be the following:—

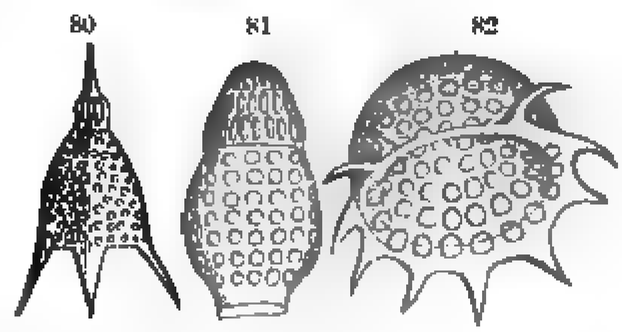
1. Actinozoöids; or, *Radiate Protozoans*, as the Sponges, Polycystines, Noctilucæ, etc. The mineral secretions, when any exist, are, with few exceptions, *siliceous*. (A few sponges have *calcareous* spicula.)

A few species are here figured. Fig. 976 represents a Spherozoum (*S. orientale* D.), a gelatine-like spheroidal mass, containing many minute circular spots, each set about with siliceous spicula (see Amer. Jour. Sci. [2] xxxv.). Fig. 979 *a* is the mass, natural size, and *b* one of the circular spots or individuals of the

Fig. 979.



Figs. 980–982.



Protozoans.—Fig. 979 *a*, Spherozoum orientale, natural size; *b*, one of the individuals in the compound mass enlarged. 980, Lychnocanium Lucerna (× 100); 981, Eucyrtidium Mongolfieri (× 100). 982, Halicalyptra fimbriata (× 75).

compound mass, enlarged. This species was obtained by the author in the Pacific in lat. 28° to 30° N., long. 178° W., where they were so abundant as to make the water look cloudy. The *Sphærozoa* are supposed to be closely related to

sponges. It is possible that the spicula of allied species may have contributed to deep-sea formations in ancient oceans. (See figs. *j*, *l*, *m*, p. 271.)

Figs. 980–982 are of *Polycystines* from the Barbadoes (p. 612); fig. 980, *Lychnocanium Lucerna* Ehr.; fig. 981, *Eucyrtidium Mongolfieri* Ehr.; fig. 982, *Halicalyptra fimbriata* Ehr., the first two magnified 100 diameters, the last about 75. From these deeply concave forms there are gradations in one direction to disks with concave centres, and to flat disks, both with plain and pointed borders, and in the other direction to elongate, conical, and spindle-shaped forms. Others have the shape of a flattened cross; another is an open diamond with narrow diagonals and periphery. The disks have a *concentric*, and not a spiral, structure, and thus are unlike those of Nummulites. For figures, see Ehrenberg's Mikrogeologie, and Bailey in Amer. Jour. Sci. [2] xxii. pl. 1.

The living Polycystines extend out fibre-like processes through pores in the shells, and in this respect are like Rhizopods.

Although probably among the earliest kinds of life, Polycystines have not yet been recognized in rocks below the Tertiary, unless an ovoidal siliceous cell found by M. C. White in the chert of the Black River limestone of Watertown, N.Y. (Amer. Jour. Sci. [2] xxxiii. 386, fig. 30), is of this nature.

2. MALACOZÖOIDS; or, *Mollusk-like Protozoans*, as the Rhizopods. The mineral secretions, when there are any, are *calcareous*, and the cells are arranged alternately or spirally (p. 164), in this resembling the Bryozoans and Gasteropods among Mollusks.

D'Orbigny's classification of the Rhizopods, given on page 164, is not a natural one; and none has yet been proposed that is free from objections.

3. ENTOMOZÖOIDS; or, *Articulate-like Protozoans*.

The *Infusoria* that are not plants nor larval forms of higher species belong to one of these three divisions. According to Agassiz, the *Vorticella* group is related to the Bryozoans among Mollusks. Other Infusoria, as the unsymmetrical *Trachelocercæ*, *Plesconiæ*, etc., may be also Mollusk-like forms. Many of the symmetrical Infusoria have been proved to be only the embryonic condition of worms; but some so related will probably prove to be true Entomozöoids. The *Amœbæ*, as has been suggested, may be larval, as is now known to be the case with the *Gregarinidæ*.

The geological importance of Rhizopods has already been explained, excepting in one respect,—their connection with *the origin of Green-sand*, a fact first observed by Ehrenberg. The Green-sand grains of the Cretaceous and other formations are found to be very generally *casts* of these shells. The material first forms within them, and then penetrates all the pores of the minute structure, and finally, on the disappearance of the carbonate of lime, it has their interior or exterior form. Bailey found this same green earth (glauconite) filling recent Rhizopod shells from the Gulf of Mexico, and from the bottom of the Atlantic beneath the Gulf Stream and in other parts; and Pourtales has since made the same observation. The latter states, however, that he found this green earth penetrating also the shells of some small *Mollusks*, *Barnacles*, and *Millepore Corals*. No chemical explanation of these facts has yet been offered. (Bailey, Amer. Jour. Sci. [2] xxii. 282; Pourtales, Rep. Coast Survey, 1859, 248.)

B.—Hudson Period (p. 217).

The *Lorraine shales* (designated in part *Pulaski shales* in the N.Y. Annual Geological Reports) were so named from the town of Lorraine, in the southern part of Jefferson co., N.Y., where the whole thickness of the beds overlying the Utica shales is well exposed. They include the western part of the Hudson River formation in the State of New York. They consist of thin beds of gray sandstone, alternating with fine argillaceous shales. The beds are in general nearly horizontal: they extend eastward along the Mohawk valley.

Although the Hudson River formation has lost a large part of its strata in the Hudson River valley by the discovery that the upturned slates of that region are of the Potsdam period, it still retains some portions on the west side of the river, enough to render it proper to continue to use the name for the formation and for the period to which it belongs. The name is now so much a part of the science in Europe, as well as in America, that any change is greatly to be deprecated.

C.—Devonian Age.

According to E. Jewett, recent observations, both stratigraphical and palæontological, by himself and J. M. Way, in Delaware co., N.Y., tend to prove that *the rocks of the so-called Catskill group are probably all Chemung*. Several fossils from distant localities have been identified with Chemung species.

Figure 983 represents in outline, half the natural size, a portion of a fossil plant from the Chemung beds, found at Wisner's quarry near Elmira, Chemung co., N.Y.,—the *Lepidodendron Chemungensis* D. (Sigillaria Chemungensis *Hall*). The specimen figured by Hall was 12½ inches long, and from 2 inches to 2½ wide.

Fig. 984.

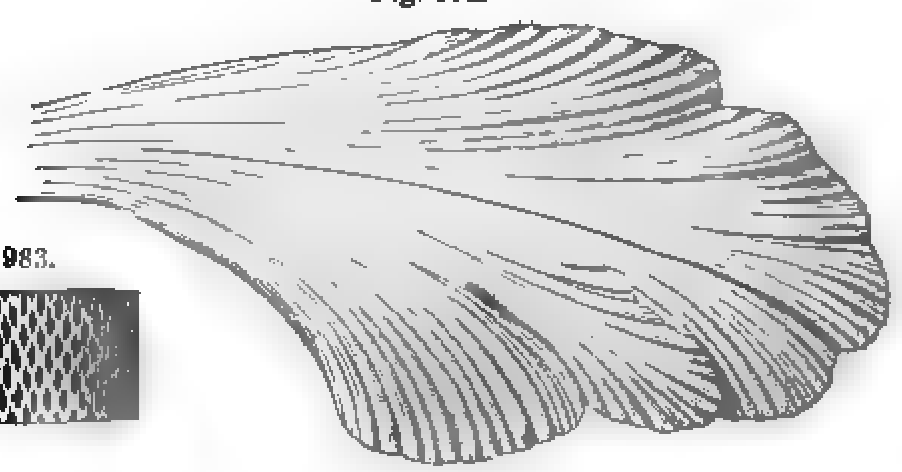


Fig. 983.

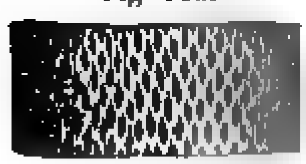


Figure 984 is a peculiar plant, a little like the Noeggerathiæ in habit, figured by H. D. Rogers on Plate 22 of the Geological Report of Pennsylvania. On the plate it is stated that it is a fossil plant from the Ponent sandstone beds, or of the Catskill period. There is no reference to it in the text. The color of the plate indicates that the rock was reddish. Is it from the *Mesozoic* of Pennsylvania?

The figure of the *Noeggerathia* on page 291 is from a portion of a very large frond on limestone, found at Montrose, Pa., by Rev. H. A. Riley.

D.—Glacial Epoch (p. 535).

Glacial scratches occur in Pennsylvania on the top of Penobscot Knob, 3000 feet above the sea-level, and on Peter's Mountain, near Harrisburg, 2000 feet. On the former, where they cover a naked face of rock at the extreme summit, three sets of scratches cross each other, diverging at angles of 25 and 30 degrees. On Peter's Mountain, horizontal scratches occur at the summit on the upright wall of a notch in the rock thirty or forty feet deep (Lesley).

In the valley of Wyoming, Pa., there is a conformity between the direction of the scratches and the course of the valley (H. D. Rogers).

On Catskill Mountain, N.Y., according to Ramsay, the scratches are numerous, and continue up to the plateau on which the hotel stands, 2850 feet above the sea; and all but a few of the highest run from *north to south* along the flanks of the escarpment, or in the direction of the Hudson River valley, and *not from west to east* down the slope of the hill. The chief grooves run between S. 22° E. and S. 55° W.; among them one runs S. 22° E., two S. 10° E., two N. and S., one S. 10° W., six S. 22° W., one S. 30° W., two S. 55° W., one W. 10° N. Ramsay observes that the variations seem connected with bends and other irregularities in the face of the great escarpment. The course S. 55° W. was found at the top, near the hotel; and in the plateau on the summit of the water-shed there are "numerous main grooves passing across the hill *at right angles to most of those observed* during the ascent" (Quart. Jour. Geol. Soc., xv. 209).

See further, for information on scratches in New York, a table by Mather, in his New York Geological Report, pages 199–206.

W. B. Dwight, in a recent communication to the author, mentions that at Cherry Valley, N.Y., there are two systems of scratches, nearly at right angles to each other, and none between the two: the directions are (1) S.S.W. to S. by E. and (2) E. by N. These courses, as he says, do not follow the slopes of the minor valleys of the region; but they do appear to correspond to the grander slopes of the land. The town lies near the summit-level, in the vicinity of the head-waters of the Susquehanna, and also on the south border of the Mohawk valley; and he suggests, with good reason, that *one system* is that of a great glacier moving southward along the wide Susquehanna slope of the plateau of southern New York, and the *other system* that of a glacier moving eastward down the Mohawk valley. The latter probably had its independent movement when the Glacial epoch was on the decline.

These interesting observations sustain the conclusion that *the features of the land have guided the courses* of the great glaciers. On page 544, evidence has been stated as to a *Connecticut-valley glacier* and a *Hudson-valley glacier*, and, also, on page 545, of a *Penobscot-Bay glacier;* and now we have evidence of a *Susquehanna-valley glacier* and a *Mohawk-valley glacier*. The absence of glacier-phenomena about many of the heights bounding the Hudson and Connecticut valleys, and the irregularity in the courses of scratches about those other summits on which they occur, serve to define the outline of the independent, or partly independent, glacier-streams.

In Missouri, unstratified Drift of the Glacial epoch abounds north of the

Missouri River, and exists in small quantities as far south as the Osage and Meramec: the thickness is from one to forty-five feet; the greatest thickness and coarsest material are to the north. The boulders or rounded stones consist of metamorphic rocks and fossiliferous limestone: the nearest locality of the former in place, according to Owen, is on the St. Peter's River, about 300 miles north of St. Joseph; the latter are from localities near where they occur, as is shown by the fossils. The largest boulders are five to six feet in diameter. The Drift is underlaid in several counties (and perhaps generally) by a layer of pipe-clay, one to six feet thick (Swallow).

There is no Drift in Arkansas, except that of a local origin (D. D. Owen).

With regard to oblique scratches up and down declivities, Professor Guyot states, in a letter to the author, that they are a common result of glacier-action in Switzerland. The most of the scratches on the Jura Mountains are of this description. As the great glacier of the Rhone moved against their sides and became deflected thereby, there was, as a resultant (on the northeast side at least), a running up obliquely of the whole mass at the same time that it moved eastward and down the general slope of the country.

To appreciate the effects of a vast glacier over a continent or occupying the whole breadth of a wide valley,—like that of the Hudson between the summit of the Green Mountains on one side and that of the Catskills on the other,—it must be remembered that a general southerly movement in the whole mass would carry the boulders and scratch surfaces, transversely or obliquely, across subordinate transverse valleys and ridges, ascending or descending declivities.

It is to be noted, in connection with this subject, that powerful torrents flow for some distance beneath all glaciers, and from their terminations; and the effects of such torrents are naturally mingled with true glacial effects.

Agassiz and Guyot, of Switzerland, who are familiar with both the Swiss and American facts, adopt the Glacier theory of the drift.

E.—Coral Reefs (pp. 587, 591).

1. *Rate of growth of corals.*—The author is indebted to Captain E. B. Hunt, U.S. Engineers, for the following definite facts with regard to the rate of growth of species at Key West, southwest of the southern cape of Florida.

Over a bottom in ten feet water which had been cleared in 1846, a Meandrina grew in the course of eleven years to a hemisphere (the usual form of the species) *six inches* in radius.

This is equivalent to six-elevenths of an inch a year; and, allowing one-third for the porosity of the coral, it corresponds to an upward increase in solid bulk of *four-elevenths* of an inch,—which is almost identical with the *three-eighths* deduced on page 591.

An *Oculina*—a branching coral growing in clumps—grew at the same place, in twelve years, to a height of nine inches and a breadth of twelve inches, equivalent to three-fourths of an inch a year. This coral has few pores; but the branches are small, being hardly a fourth of an inch thick at the extremity, and the spaces between them are from one to one and a half inches. The amount of increase is not equal to that of the *Meandrina*.

2. *Florida reefs.*—The rock of the reef at Key West is mainly an oolitic lime-

stone, usually a little friable and in some parts becoming brecciated. It forms just above the water-level, and also below the surface to a depth of several—perhaps many—feet. This variety of rock is uncommon among the extensive reefs of the Pacific, the kind most approaching it being a sea-shore rock made from coral sands. The rock there formed from coral mud or sand at moderate depths in the lagoon and off shore is a white, compact, unfossiliferous limestone, having the flint-like fracture of the Bird's-eye limestone (of the Trenton period) in central New York (p. 206).

The origin of the long curving line of coral reef stretching southwestward from southern Florida to the Tortugas, and having a total length of 120 miles, has been satisfactorily explained by Captain Hunt, who attributes the prolongation to the transportation of coral sands from the coral reef to the eastward by the Labrador current (p. 657). He shows that the current is just such as would produce the form presented by the reef. This barrier-reef has, therefore, the same origin as those of siliceous sands farther north on the American coast. The only difference is this: that the material of which the sand of the coral reef is made is a result of the growth of animal life on an earlier part of the reef. The sound between the reef and Florida is about 120 feet deep, and has a bottom of clean coral sand, the material of which, as Captain Hunt shows, is washed from the reef. It is still possible that a subsidence has *aided* in producing the results.

3. *Soundings near coral islands.*—Among the Paumotus, according to Wilkes, southeast of Ahii, the lead struck at 150 fathoms, and then fell off, and finally brought up at 300 fathoms; 2 miles east of Serle's Island, no bottom was found at 600 fathoms; 1½ miles south of the larger Disappointment Island, no bottom at 550 fathoms; a mile from the east end of Metia, no bottom at 600 fathoms. Off Whitsunday Island, Beechey found no bottom at 250 fathoms. Darwin states that Lieut. Powell found, 600 feet from Diego Garcia, no bottom with 150 fathoms; that at Cardoo Atoll Island, 300 feet off, no bottom was obtained at 200 fathoms; 2200 yards from Keeling Island, Fitzroy found no bottom at 1200 fathoms; but the line at a depth between 500 and 600 fathoms was partly cut, as if it had rubbed against a projecting ledge of rock.

These facts bear on the question of the thickness of coral reefs.

4. *Chalk.*—The only locality of chalk among the Pacific coral-reef rocks, observed by the author, occurs on the island of Oahu (Hawaian group). It has but a few yards of extent, and is situated close by an injected dike of lava; and it is probable that it owes its origin in some way to heat connected with the injection. The author regards it, therefore, as no true exception to the statement made on page 617 that chalk is not one of the varieties of coral rock: it is made by accumulations of Rhizopod shells, and not of coral or shell sand.

F.—Progress of Life (pp. 596, 597).

Dividing the Animal kingdom into Invertebrates and Vertebrates as the two subdivisions, the Cephalopods (Orthocerata, etc.) may perhaps be regarded as the comprehensive type, foreshadowing the latter, as explained on page 397.

The internal bone in Cephalopods, mentioned on p. 397, exists only in those

species that have no external shell. The earliest of this kind were probably the *Conulariæ*, as already stated.

Page 597.—In the sub-kingdom of *Radiates* there are two comprehensive types intermediate between the classes of Polyps (the *inferior*) and Acalephs (the *next higher*). (1.) That of the *Cyathophylloid corals*, whose fundamental structure is based on the number 4, the number eminently characteristic of Acalephs, the rays being multiples of *four*, and not (as in modern corals) of *six*. (2.) That of the *Favosites family of corals*, which, if related to modern Millepores and true Acalephs, as Agassiz holds (p. 162), belong to that division of Acalephs which embraces species so polyp-like that until recently they were arranged with Polyps. The species of these comprehensive types are the only known representatives of Polyps and Acalephs in the Palæozoic faunas, excepting possibly the Graptolites; and these, if Acalephs (p. 190), are Hydroids like the Favosites.

Coral-making Mollusks (Bryozoans), Polyps, and Acalephs, were a prominent part of that *harmonious* assemblage of groups which constituted the life of the Palæozoic.

G.—Mineral Oil.

Mineral Oil, or Petroleum, is a bituminous liquid resulting from the decomposition of marine or land plants (mainly the latter), and *perhaps*, also, of some non-nitrogenous animal tissues. It proceeds from rocks of various ages, from the Lower Silurian to the Post-tertiary, and from limestones and sandstones, as well as shales. The so-called *anthracite* of the *Calciferous* beds of New York is, according to T. S. Hunt, an altered and inspissated mineral oil; and liquid drops of the original material sometimes exist in the quartz crystals of the same region. In the *Bird's-eye limestone* of Rivière à la Rose (Montmorenci), Canada, and of Watertown, N.Y., it flows in drops from a fossil coral; and in the *Trenton limestone* at Pakenham, Canada, it fills the cavities of large Orthocerata. It proceeds from the *Hudson River formation* in Guelderland, near Albany, and occurs on the surface of a spring and issues from the *Utica slate* on Great Manitoulin Island (Lake Huron). The *Niagara* limestone sometimes affords traces of it; and so also do the Medina red shales.

The *Corniferous* beds of the Devonian afford petroleum at Black Rock in the Niagara River, where it occupies cavities in fossils; and, in sufficient abundance to be an object of commerce, at Enniskillen in Western Canada, near which place there is, over the surface, a deposit of solid bitumen or mineral tar, half an acre in extent, probably derived from the limestone beds below.

The *Marcellus shales*, or lower part of the *Hamilton* group, and also the upper part of the same, contain occasionally concretions which enclose petroleum. The rocks of the *Chemung* period afford abundant oil-springs in Erie, Seneca, and Cattaraugus counties, New York. The oil-wells of Pennsylvania and Ohio are sunk in Devonian or Subcarboniferous sandstones, often descending through overlying Carboniferous strata. Some of the most noted "wells" in these regions are at Mecca in Trumbull co., Ohio, Titusville on Oil Creek in Pennsylvania, and near the Little Kanawha in Virginia.

In the American Mesozoic, a liquid petroleum occurs in Triassic shales and limestone at Southbury, Ct.

The petroleum of the island of Trinidad arises from the Tertiary formation. Mineral oil is a compound of hydrogen and carbon. The composition varies between $C_{18}H_{20}$ and $C_{28}H_{28}$. In becoming inspissated it is often more or less oxydized, losing sometimes in part its fusibility and its solubility in ether.

See further, on this subject, a paper by E. B. Andrews in the Amer. Jour. Sci. [2] xxxii. 85, and one by T. S. Hunt in the Canadian Naturalist and Geologist, vi. 241, August, 1861, from which the larger part of the above facts have been cited.

H.—Catalogue of American Localities of Fossils.

The following catalogue of American localities of fossils contains only some of the more important, and is intended for the convenience especially of the student-collector.

Localities of Fossils.

Potsdam sandstone.—Swanton, Vt.; Braintree, Mass.; Keeseville (at "High Bridge"), Alexandria, N.Y.; Chiques Ridge, Pa.; Falls of St. Croix, Osceola Mills, Trempaleau, Wisconsin; Lansing, Iowa; St. Ann's, Isle Perrot, C.W.; near Beauharnois on Lake St. Louis, C.E.

Calciferous.—Point Levi, Mingan Islands, Philipsburg, and near Beauharnois, C.E.; Grand Trunk Railway between Brockville and Prescott, St. Ann's, Isle Perrot, C.W.; Amsterdam, Fort Plain, Canajoharie, Chazy, Lafargeville, Ogdensburgh, N.Y.

Chazy limestone.—Chazy, Galway, Westport, N.Y.; Island of Montreal, C.E., 1 to 3 miles north of "the Mountain."

Bird's-eye limestone.—Amsterdam, Little Falls, Fort Plain, Adams, Watertown, N.Y.

Black River limestone.—Watertown, N.Y.; Ottawa, C.W.; Island of Montreal, and near Quebec, C.E.

Trenton limestone.—Adams, Watertown, Boonville, Turin, Jacksonburgh, Little Falls, Lowville, Middleville, Fort Plain, Trenton Falls, N.Y.; Pine Grove, Aaronsburg, Potter's Fort, Milligan's Cove, Pa.; Highgate Springs, Vt.; Montmorency Falls and Beauport Quarries near Quebec, Island of Montreal (quarries N. of the city), C.E.; Ottawa, Belleville, Trenton (G. T. R. R., W. of Kingston), C.W.; Copper Bay, Mich.; Elkader Mills, Turkey River, Dubuque, Iowa; Falls of St. Anthony, St. Paul, Mineral Point, Cassville, Beloit, Quimby's Mills near Benton, Wis.; Warren, Illinois.

Utica slate.—Turin, Martinsburgh, Lorraine, Worth, Utica, Cold Spring, Oxtungo and Osquago Creeks near Fort Plain, Mohawk, Rouse's Point, N.Y.; Rideau River along R. R. at Ottawa, bed of river two miles above, C.W.

Hudson River group.—Pulaski, Rome, Lorraine, and Boonville, N.Y.; Penn's Valley, Milligan's Cove, Pa.; Oxford, Cincinnati, O.; Madison, Ind.; Anticosti, opposite Three Rivers, C.E.; Weston on the Humber River, nine miles W. of Toronto, C.W.; Little Makoqueta River, Iowa; Savannah, Green Bay, Wis.; Scales Mound, Ill.; Drummond's Island, Mich.

Medina sandstone.—Lockport, Lewiston, Medina, Rochester, N.Y.; Long Narrows below Lewistown, Pa.

Clinton group.—Lewiston, Lockport, Reynolds' Basin, Brockport, Rochester, Wolcott, New Hartford, N.Y.; Thorold on Welland Canal, Hamilton, Ancaster, C.W.

Niagara.—Lewiston, Lockport, Rochester, Wolcott, N.Y.; Thorold, Hamilton, Ancaster, C.W.; Anticosti, C.E.; Arisaig, Nova Scotia; Racine, Waukesha, Wis.; Marblehead on Drummond's Island, Michigan. (*Coralline limestone.*—Schoharie, N.Y.)

Onondaga Salt Group.—Buffalo, Williamsville, Waterville, Jerusalem Hill (Herkimer co.), N.Y.

Leclaire limestone.—Leclaire, Ill.

"Galt" or "Guelph" formation.—Galt, Guelph (G. T. R. R.), C.W.

Lower Helderberg limestones.—Dry Hill, Jerusalem Hill (Herkimer co.), Sharon, East Cobleskill, Judd's Falls, Cherry Valley, Carlisle, Schoharie, Clarksville, Athens, N.Y.; Gaspé, C.E.

Oriskany sandstone.—Oriskany, Vienna, Carlisle, Schoharie, Catskill Mountains, N.Y.; Cumberland, Md.; Moorestown and Frankstown, Pa.

Cauda-Galli Grit.—Schoharie (Fucoides Cauda-Galli), N.Y.

Schoharie Grit.—Schoharie, Cherry Valley, N.Y.

Upper Helderberg limestones.—Black Rock, Buffalo, Williamsville, Lancaster, Clarence Hollow, Stafford, Le Roy, Caledonia, Mendon, Auburn, Onondaga, Cassville, Babcock's Hill, Schoharie, Cherry Valley, Clarksville, N.Y.; Port Colborne, and near Cayuga, C.W.; Columbus, Delaware, Sandusky, O.; Mackinac, Little Traverse Bay, Dundee, Monguagon, Mich.

Marcellus shales.—Lake Erie shore, ten miles S. of Buffalo, Lancaster, Alden, Avon, Leroy, Marcellus, Manlius, Cherry Valley, N.Y.

Hamilton group.—Lake Erie shore, Eighteen Mile Creek, Hamburgh, Alden, Darien, York, Moscow, Bloomfield, Bristol, Seneca Lake, Cayuga Lake, and Skaneateles Lake, Pompey, Cazenovia, Delphi, Bridgewater, Richland, Cherry Valley, Seward, Westford, Milford, Portlandville, N.Y.; Widden Station (G. T. R. R.), near Port Sarnia, C.W.; New Buffalo, Independence, Iowa; Rock Island, Ill.; Thunder Bay, Little Traverse Bay, Mich.; Nictaux, Bear River, Moose River, Nova Scotia.

Genesee slate.—Banks of Seneca and Cayuga Lakes, Lodi Falls, Mount Morris, two miles S. of Big Stream Point, Yates co., N.Y.

Portage group.—Eighteen Mile Creek, Lake Erie shore, Chautauqua Lake, Genesee River at Portage, Flint Creek, Cashaqua Creek, Nunda, Seneca and Cayuga Lakes, N.Y.

Chemung group.—Rockville, Philipsburgh, Jasper, Greene, Chemung Narrows, Troopsville, Elmira, Ithaca, Waverly, Hector, Enfield, N.Y.; Gaspé, C.E.

Catskill group.—Fossils rare.—Richmond's quarry above Mt. Upton on the Unadilla, Oneonta, Oxford, Steuben co. south of the Canisteo, N.Y.; Blossburg, Pa.; Pompton, Old Boonton, Pluckamin, N.J.

Subcarboniferous.—Burlington, Keokuk, Iowa; Quincy, Warsaw, Alton, Kaskaskia, Chester, Ill.; Bloomington, Spergen Hill, Ind.; Hannibal, St. Genevieve, St. Louis, Mo.; Willow Creek, Battle Creek, Holland, Grand Rapids, Mich.; Mauch Chunk, Pa.; Red Sulphur Springs, Pittsburg Landing, Tenn.; Big Bear and Little Bear Creeks, Big Crippled Deer Creek, Miss.; Clarksville, Huntsville, Ala.; Windsor, Horton, Nova Scotia.

Carboniferous.—South Joggins, Pictou, Sydney, Nova Scotia; Wilkesbarre, Shamokin, Tamaqua, Pottsville, Minersville, Tremont, Greensburg, Carbondale, Port Carbon, Lehigh, Trevorton, Johnstown, Pittsburg, Pa.; Pomeroy, Marietta, Zanesville, Cuyahoga Falls, Athens, Ohio; Charlestown, Clarksburg, Kanawha Salines, Wheeling, Va.; Saline Company's mines, Gallatin co., Terre Haute, Springfield, Ill.; Bell's, Casey's, and Union Mines, Crittenden co., Hawesville and Lewisport, Hancock co., Breckinridge, Giger's Hill, Mulford's Mines, and Thompson's Mine, Union co., Providence and Madisonville, Hopkins co., Bonharbour, Daviess co., Ky.; Muscatine, Alpine Dam, Iowa; Leavenworth, Indian Creek, Grasshopper Creek, Juniata, Manhattan, Kansas.

Triassic.—Southbury, Middlefield, Portland, Conn.; Turner's Falls, Sunderland, Mass.; Phœnixville, Pa.; Richmond, Va.; Deep River and Dan River coal fields, N.C.

Cretaceous.—Upper Freehold, Middletown, Marlboro', Blue Ball, Deal, Squankum, Shark River, Monmouth co., Pemberton, Vincenton, Burlington co., Blackwoodtown, Camden co., Mullica Hill, Gloucester co., Woodstown, Mannington, Salem co., New Egypt, Ocean co., N.J.; Warren's Mill, Itawamba co., Tishomingo Creek, R. R. cuts, Hare's Mill, Carrollsville, Tishomingo co., Plymouth Bluff, Lowndes co., Chawalla Station (M. & C. R. R.), Ripley, Tippah co., Noxubee, Macon, Noxubee co., Kemper, Pontotoc and Chickasaw counties, Miss.; Tuscaloosa, Ala.; Fox Hills, Sage Creek, Long Lake, Great Bend, Cheyenne River, etc., Nebraska.

Eocene.—Everywhere in Tippah co.; Yockeney River; New Prospect P. O., Winston co.; Marion, Lauderdale co.; Enterprise, Clarke co.; Jackson; Satartia, Yazoo co.; Homewood, Scott co.; Chickasawhay River, Clarke co.; Winchester, Red Bluff Station, Wayne co.; Vicksburg, Amsterdam, Brownsville, Warren co.; Brandon, Byram Station, Rankin co.; Paulding, Jasper co., Miss.; Claiborne, Monroe co., St. Stephen's, Washington co., Ala.; Charleston, S.C.; Tampa Bay, Florida; Fort Washington, Fort Marlborough, Piscataway, Md.; Marlbourne, Va.; Brandon, Vt.; Cañada de las Uvas, Cal.

Miocene.—Gay Head, Martha's Vineyard, Mass.; Shiloh, Jericho, Cumberland co., N.J.; St. Mary's, Easton, Md.; Yorktown, Suffolk, Smithfield, Richmond, Petersburg, Va.; Astoria, Willamette River, Oregon; San Pablo Bay, Ocoya Creek, San Diego, Monterey, San Joaquin and Tulare Valleys, Cal.; White River, Upper Missouri Region.

Pliocene.—Ashley and Santee Rivers, S.C.; Platte and Niobrara Rivers, Upper Missouri.

I.—Brief Synopsis of this Manual.

This synopsis is intended to serve as a basis for a short course of instruction, such as may be desired in Institutions not strictly scientific.

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J.—Authorities for the Sections, Views, and figures of Fossils in this work.

The following are the authorities for the more important illustrations of this Manual. The works mentioned are those from which the figures or views have been taken; and although generally the original publications, they are not all so. When the figures have been made from original drawings not before published (the fact with regard to about 150), the reference is distinguished by annexing a point of interjection (!). Many of the new figures by Meek under the Mesozoic and Cenozoic are from a manuscript Palæontological Report of Lieut. G. K. Warren's Expedition to the Upper Missouri, by Messrs. Meek and Hayden, the publication of which, unfortunately for science, has been deferred.

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Physiographic Chart, by the Author, excepting the Topography of the Continents by A. Guyot.

K.—Scientific Nomenclature.

As words derived from the Greek, whether Latin (the language of the nomenclature of Natural Science) or English, are often written incorrectly, some of the more common rules of orthography are here mentioned:—

1. The Greek κ becomes c in Latin and English. Thus, from Κικερων (Kikerōn) comes *Cicero*; from κεντρον (kentron) come *centrum* in Latin and *centre* in English. Other examples are *circle, cephalic, microscope, catalogue.*

2. The Greek αι becomes æ in Latin and *e* in English. Thus, from αιθηρ (aither) come *æther* in the former and *ether* in the latter; from καινος (kainos) and ζωον (zōon) comes *cenozoic;* from *æqualis* in Latin comes *equal,* from *ædificium, edifice.* Palæontology would be correctly spelt *Palæontology,* although seldom so done.

3. The Greek οι becomes œ in Latin and œ or *e* in English. Thus, from οικονομια (oikonomia) come *œconomia* and *economy.*

4. The Greek υ becomes *y* in Latin and English. Thus, from συνοψις (sunopsis) comes *synopsis;* from μυτιλος (mutilos) *mytilus;* from Αιγυπτος (Aiguptos) come *Ægyptus* and *Egypt.*

5. The Greek terminations ος and ον become in Latin *us* and *um.*

6. In compounding words, the first one takes the genitive form, and if Greek, *o* is made its final letter, if Latin, *i;* but this vowel is in each case dropped when the following word begins with a vowel. Thus, from ων (gen. οντος) and λογος comes *Ontology,* as in the word Palæontology; and, in the same word, the first part, derived from παλαιος, loses the final *o;* from *crux* (gen. *crucis*) comes *cruciform;* from *penna, penniform* (not *pennæform*).

7. Specific names named after a locality should end in *ensis,* as *Canadensis* from Canada; after an individual not the discoverer, in *anus,* as *Sayanus* from Say; after the discoverer, they should take the form of the genitive, as *Vanuxemi* from Vanuxem.

The initial letter of specific names, in this Manual, has been made a capital when derived from the name of a place or that of a person, and when a substantive.

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NOTE.—An asterisk (*) after the number of a page indicates that there is a reference on the page to a *figure* of the species or object mentioned; and a section-mark (§) implies that the page contains a *definition*, *explanation*, or *characteristic* of the word or object mentioned.

THE END.

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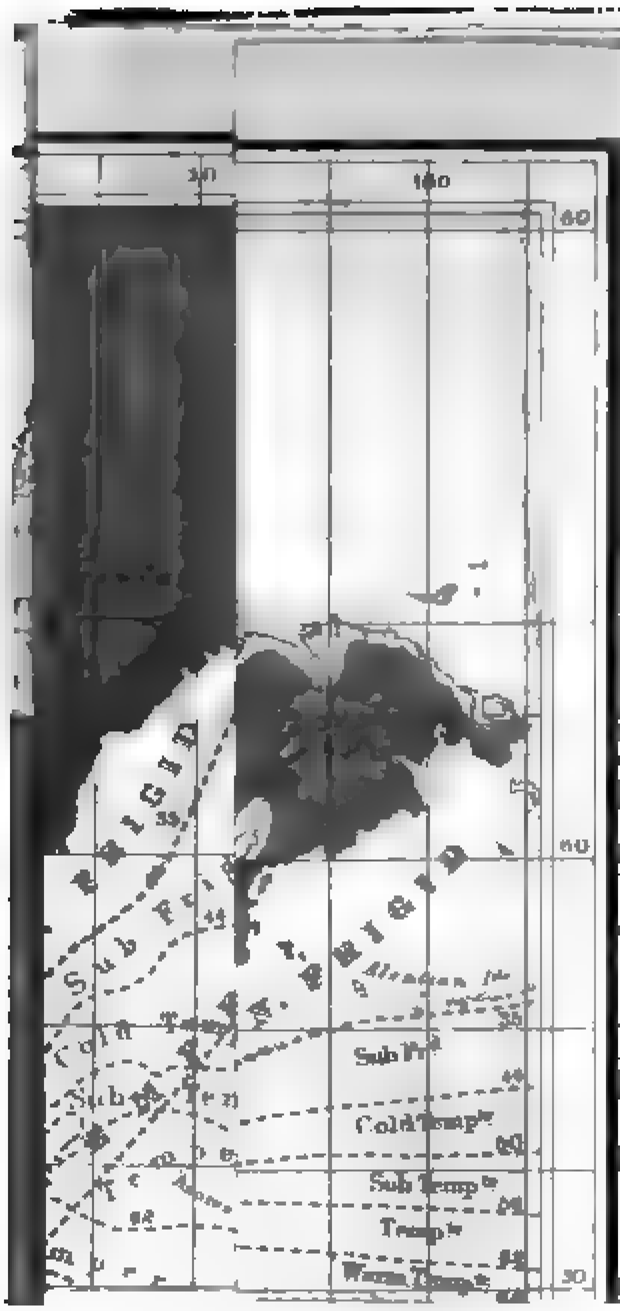

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Sub Temp
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